REPORT 29

SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMÉLIORATION

DU MILIEU PÉDOLOGIQUE

ET AQUATIQUE

Canadä

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

100-05259/

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

THE EFFECT OF ORGANIC MULCHES ON SOIL MOISTURE AND CROP GROWTH

FINAL REPORT

August, 1991

Prepared by:	Dr. T.J. Gillespie, DEPARTMENT OF LAND RESOURCE SCIENCE, Dr. C.J. Swanton, DEPARTMENT OF CROP SCIENCE, C.S. Wagner Riddle, DEPARTMENT OF LAND RESOURCE SCIENCE, UNIVERSITY OF GUELPH, Guelph, Ontario
Under the Direction of:	ECOLOGICAL SERVICES FOR PLANNING LIMITED, Guelph, Ontario - Subprogram Manager For TED
On Behalf of:	AGRICULTURE CANADA RESEARCH STATION, HARROW, ONTARIO N0R 1G0

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Many of the advantages of the conservation tillage systems currently in use derive from the presence of crop residue on the soil surface. Crop residues reduce soil erosion losses, therefore increase soil water infiltration, and decrease soil water loss by evaporation (Griffith et al., 1986).

Additionally, crops can be grown specifically for the purpose of covering the soil during periods between main crops, to then be killed and left as a mulch on the soil surface before planting of the main crop. The management practices used in the spring will then influence the value and effectiveness of cover crops (Triplett, 1986).

The timing of killing of the cover crop is a critical decision dependent on climate. Adequate amounts of mulch have to be present after killing, to assure that the soil water conserving properties of the mulch are maximized. On the other hand, delay in the timing of killing can have adverse effects on subsequent crop growth if soil water is limiting, such as during a dry spring or on soils with low water holding capacity. During a wet spring, the possibility of removal of excessive moisture by the growing cover crop suggests that a late killing could allow the timely planting of the main crop.

In addition to the soil water conserving properties of a mulch, effects such as a decrease in soil temperature variations can be a advantage for the growth of the subsequent crop, and should be considered in the management practices of the cover crop.

Winter rye is among the cover crops extensively used due to its winter hardiness, low fertility tolerance, early spring growth and persistence of the mulch produced (Moschler et al., 1967). In this study, soybeans were chosen as a standardized main crop and winter rye was used as the preceding cover crop on a sandy, a loam and a clay soil.

The use of a model linking climate to the effect of a rye mulch on soybean growth would be very useful in determining optimum management of the cover crop for various weather scenarios.

Therefore, the main research objectives of this project were:

1) to study the timing of rye killing in a rye/soybean system, where the rye is planted in the fall, chemically killed and mowed in the spring, and soybeans are no-tilled through the rye mulch;

2) to investigate the effect of a rye mulch on soybean growth and yield;

3) to measure the effect of rye mulch on soil water and soil temperature.

4) to model the effect of a rye mulch on soybean growth under various weather scenarios.

The rye mulch/soybean system studied proved satisfactory for soybean production on a sandy and a loam soil. On a clay soil, difficulties associated with excess fall moisture and winter kill interfered with cover crop establishment, while planter problems and slug damage in the spring decreased soybean yield on mulched plots. More research would be necessary if the system is to be adapted to clay soils, but our experience was not encouraging.

On the sandy and the loam soil site, rye mulch amount was significantly larger for the late killing date as opposed to an early killing date. Differences between soil drying rates under early killed rye mulch and late killed rye mulch were observed in 1990 at Delhi, but generally soil water content between the two mulch treatments was not different. Soil water conservation under mulch, although significant for short periods early in the season during one year, did not affect early soybean growth due to timely rainfalls.

For rye mulch amounts larger than 2000 kg/ha, no significant increases in percentage ground cover were gained by delaying rye cover crop killing. Also, mulch decomposition proceeded at a faster rate for large mulch amounts.

Although the rye mulch had a significant effect on the soil surface drying rate early in the soybean growing season, shading of the soil surface by the soybean canopy plus a substantial decrease

in the amount of mulch present on the soil surface, resulted in little difference between mulch and no mulch conditions later in the season.

Analysis of hourly soil temperatures measured under mulch and no mulch treatments revealed that extreme temperatures are more frequent under the bare soil condition. Over the whole growing season these differences were limited to a small percentage of hours, but the lower variability of temperature under the mulch may have benefited microbial activity and root growth slightly.

The change in the moisture and temperature regimes of the soils studied, induced by the presence of a rye mulch on the soil surface, did not result in significant soybean yield increases or decreases. Delays or decreases in soybean emergence observed for some treatment-years were compensated by the plants as the seasons progressed. If other beneficial aspects of the no-tillage system are considered, such as reduced soil erosion (Phillips et al., 1980), and, weed suppression (Weston, 1990), rye mulch is recommended to be used in no-till soybeans.

A rye mulch/soybean computer simulation model was constructed, using the CERES-Wheat and SOYGRO as building blocks. The water balance subroutine (WATBAL) used in SOYGRO was modified to include the effect of rye mulch on soil evaporation and rainfall interception. Good agreement between simulated and observed soil water content, rye biomass, and soybean pod yield was obtained even with data that was not used to calibrate the models. Based on the simulation results obtained, killing the rye cover crop approximately one week before soybean planting resulted in the best soybean yields under a variety of simulated rainfall conditions, on both medium and sandy textured soils.

Section 1 - INTRODUCTION

1.1. Mulches

Mulch can be defined as any material on the soil surface through which continuous liquid water films from the soil are not present (Phillips, 1984). The traditional mulch consists of a well-aerated, and therefore poorly conducting, surface cover, such as straw, leaf litter or gravel (Oke, 1987).

Hanks et al. (1961) remarked that the practice of mulching is probably as old as agriculture itself and that the usual purposes of surface treatment by some type of mulch were to prevent water loss by evaporation, to influence soil temperature, or to minimize weed growth. Blevins et al. (1983) considered the presence of additional plant residue on the soil surface one of the most prominent features of conservation tillage systems when compared with moldboard plow tillage.

Crop residues affect soil water content by having a direct effect on the evaporation from the soil surface and on the amount of water that infiltrates into the soil. Decreases in infiltration due to sealing of the pores caused by raindrop impact are reduced by residue cover. Crop residues significantly influence evaporation by affecting: 1) net radiation due to changes in surface albedo, 2) aerodynamic vapour conductance due to changes in wind speed, 3) resistance to vapour diffusion, which is dependent on mulch thickness, tortuosity and volumetric air fraction (Van Doren and Allmaras, 1978).

The surface residue affects the absorption of solar radiation, and decreases the thermal admittance of the surface relative to that of bare soil, so that more of the absorbed radiant heat goes to the atmosphere, thus decreasing the energy available to heat the soil. Soil warming is also affected by the evaporation under a mulch relative to a bare soil, and the decrease in sensible heat transfer between overlying air and the soil (Tanner et al., 1987).

Several laboratory and field studies have demonstrated that the presence of a mulch on the soil surface increases soil water content (Jones et al., 1969; Blevins et al, 1971; Greb et al.,

1967; Unger, 1978; Steiner, 1989) and decreases soil temperature in relation to a bare soil (Griffith et al., 1973; Gupta et al., 1983; Johnson and Lowery, 1985; Unger, 1988).

Bond and Willis (1969) showed that evaporation rates from soil columns treated with various rates of rye straw, measured during the initial constant drying stage, decreased with increasing residue rates. Reduction in soil water evaporation compared to a bare soil was around 20% and 90% for the 560 kg/ha and 17920 kg/ha straw rates, respectively. The effect lasted only a few days for the lower straw rate and 60 days for the higher rate.

Groenevelt et al. (1989) remarked that mulches modify the following evaporation parameters: 1) the drying coefficient (k), an index of relative soil drying rate; 2) the soil boundary coefficient (k_b), an index of relative evaporation; and 3) the diffusivity (D_w), the effective rate of transport of water to the surface. In their laboratory experiment, rock mulches reduced k and D_w by an order of magnitude and k_b by approximately 25% compared to bare soil.

Enz et al. (1988) used lysimeters in a field study in North Dakota. More evaporation was measured from a bare surface as compared to a wheat stubble covered surface (3400 kg/ha), until the bare surface was dry. Then the stubble covered surface had larger evaporation due to its greater available water. The monitored daily net radiation was always greater for the bare soil surface. The bare soil had higher temperatures than the stubble covered surface except for overcast conditions with wet surfaces when they were about equal.

In a comparison of various surface residue-tillage treatments, maximum temperature differences were 12 and 19 C, respectively for fall and spring, between no residue and surface residue treatments for the same tillage condition (Gupta et al., 1983).

1.2. Rye Cover Crop

Rye planted as a cover crop has been extensively used to produce a mulch on the soil surface after chemical killing (Moschler et al., 1967; Gallaher, 1977; ;Campbell et al., 1984;

Eckert, 1988; Munawar et al., 1990; Raimbault et al., 1990; Weston, 1990).

Advantages of the rye plant over other cereals have been described as its extreme winter hardiness, ability to grow in sandy soils of low fertility, most highly developed root system of all cereals and 20-30% less water use per unit dry matter formation than wheat (Bushuk, 1976). Early rye spring growth and production of relatively large amounts of persistent mulch have also been cited (Moschler et al., 1967).

In another study, rye and wheat mulches provided the greatest seedling establishment with greatest weed suppression for several weeks after cover crop kill (Weston, 1990). These cover crops were also easily and inexpensively controlled by low rates of glyphosate.

A living cover crop uses stored soil moisture and delaying the killing of a cover crop can have adverse effects on the crop that follows. In a dry spring, the rye cover crop accelerated soil water use and resulted in lower soybean yields under conservation tillage in a study conducted in the U.S. southeastern coastal plain (Campbell et al., 1984). In one of the years of a Kentucky study (Munawar et al., 1990), dry matter production of late-kill rye doubled during the two to three week period from early kill, and soil moisture was significantly greater with the early killed rye than with the late-killed rye treatment during the early part of the season. Corn yields were significantly greater with early killed rye than with late-killed rye in both study years.

But, early killing limits dry matter production and the succulent herbage decomposes rapidly (Griffith at al., 1986). Munawar et al. (1990) concluded that in a high rainfall spring it may be advantageous to allow the cover crop to grow longer to dry out the soil and produce more dry matter for surface mulch, which would conserve water more efficiently for the corn crop during the summer. The additional mulch produced by late versus early rye killing tended to increase corn yields, though not always significantly, in a 11 location-year study in Virginia (Moschler et

al., 1967).

Raimbault at al. (1990) concluded that the use of rye as a cover crop preceding corn could significantly delay maturity and/or lower corn yield. They suggested that an early killing followed by 2-3 weeks fallow period prior to corn planting may eliminate the apparent allelopathic effect of the rye on the following corn crop.

The varying results from a number of studies cited above point out that the optimum timing of killing for the cover crop is an important management decision.

1.3. Soybeans

The effect of mulches or crop residues on soybean yields have been evaluated by several tillage comparisons studies. Tillage effects on yield in some years were often not significant (Tyler and Overton, 1982; Campbell at al., 1984; Tollner et al., 1984; Elmore, 1987; NeSmith et al., 1987; Edwards et al., 1988; Deibert, 1989; Deibert and Utter, 1989; Elmore, 1990).

In other years, mainly with precipitation lower than normal, significant yield advantages due to soil moisture conservation have been reported for the no-tillage system (Gallaher, 1977; Tyler and Overton, 1982; Campbell et al., 1984; Wilhelm et al., 1986; Webber III et al., 1987; Edwards et al., 1988; Deibert, 1989; Deibert and Utter, 1989).

Reduced soybean yields were observed with the no-tillage system in other studies due to reduction in plant stand (Eckert, 1988), poor weed control (Lindemann et al., 1982) and higher than average rainfall (Weber III et al., 1987).

The variability in the type of soybean yield response to tillage systems in the studies described is partly related to the differing weather conditions from year to year. Yield advantages should be expected in a drier than normal year, since the beneficial effects of residues present on the soil surface in no-tillage systems are mainly due to soil water conservation (Blevins et al., 1983). Griffith et al. (1986) have pointed out that the soil moisture saved through reduced tillage systems assumes great importance in regions of low rainfall and high evapotranspiration,

on soils low in water holding capacity, and in years with below normal precipitation.

The effectiveness of mulches in enhancing soybean yields is restricted to certain time periods by the fact that the magnitude of soybean seed yield reduction that occurs due to water stress is dependent on the phenological timing of that stress. Huck et al. (1986) demonstrated that differences in final seed yield between stressed and non-stressed soybean plants varied markedly from year to year, depending on the developmental stage at the time when drought stress occurred. Irrigation studies have shown that water stress occurring during late pod development and seed enlargement reduced soybean seed yields considerably below non-stressed controls (Brady et al., 1974; Doss et al., 1974; Sionit and Kramer, 1977; Korte et al., 1983a; Kadhem et al., 1985a). Other studies have indicated that water supply during flowering is as important as that during later reproductive development (Runge and Odell, 1960; Thompson, 1970; Ashley and Ethridge, 1978).

Ashley (1983) describes the remarkable capacity of the soybean plant to adapt to water stress in, for example, compensating flower and pod drop in the lower part of the plant by producing more pods in the upper nodes. After pod number becomes fixed, changes in seed size constitute the primary mode of yield response to water availability. Water stress occurring during the vegetative stages can affect seed yield if it reduces the number of plants per unit area and the number of main-stem nodes per plant in such a degree that the subsequently developing yield components (pods per node, seeds per pod and weight per seed) cannot be adjusted to compensate for that yield loss (Korte et al., 1983b).

The decreases in soybean yields mentioned above have not been associated with the lower soil temperatures that occur under no-tillage systems. Soil temperature did not consistently influence soybean emergence in a phytotron (Muendel, 1986) and a field study (Fehr at al., 1973). Seeding when soil temperature is above 10 C was recommended for Southern Alberta (Muendel, 1986). In contrast, depressed corn growth and slower corn development in conservation

tillage systems have been frequently associated with colder spring soil temperatures (Moody et al., 1963; Eckert, 1988; Fortin and Pierce, 1990). This is likely because corn is generally planted considerably earlier than soybeans.

In other studies, soil temperature has been found to be an important environmental variable influencing dinitrogen (N_2) fixation rates (Sinclair and Weisz, 1985). In a field experiment, these authors found significant positive correlations between acetylene reduction rates and soil temperatures below 30 C. Between 30 and 33 C little change in acetylene reduction with soil temperature was observed and above 34 C declines in reduction rates were observed. Therefore, cooler temperatures under mulch in the hottest periods of the growing season may positively affect nitrogen fixation.

1.4. Crop Growth Models

The development of agricultural crop growth models goes back at least 65 years (Joyce and Kickert, 1987). A large number of plant growth models for agricultural plant studies have been published during the last 25 years (Whisler et al., 1986).

Several soybean models have been developed (Meyer et al., 1979; Wann and Raper, 1979; Rudd et al., 1980; Wilkerson et al., 1983). The soybean crop growth model SOYGRO was developed as part of a project to aid farm management decision-making processes (Wilkerson et al., 1983). It was subsequently used to evaluate real-time irrigation decisions (Swaney et al., 1983) and to develop irrigation management strategies for a center pivot irrigation system (Hood et al., 1987).

The most recent version of SOYGRO (V5.42) predicts dry matter growth, leaf area index, crop development, and final yield of soybean depending on daily weather data for specific soils (Jones et al., 1989). Soil parameters that describe the ability of the soil to store and to supply water to plant roots are used in a soil water balance subroutine based on processes of runoff, percolation, and redistribution of water (Ritchie, 1985). This water balance model does not include the effect of mulches on soil evaporation

and soil temperature.

Few models describing the effect of mulch on the soil water content and soil temperature have been published (Gupta et al., 1982; Bristow, 1983; Ross et al., 1985; Chung and Horton, 1987; Steiner, 1989). Some of the published models are complex, physically-based models, have very short time steps and need detailed inputs of parameters (Bristow, 1983). Other models have described the mulch effect based on regression curves and other empirical relations (Gupta et al., 1982).

There is clearly a need for a mulch model with time step and level of detail compatible with current crop growth models. Such a model will be described in this report and validated through comparison of simulation results with data obtained in mulch field experiments. Incorporation of this mulch submodel into existing crop growth models will then be evaluated through further comparison with experimental results.

1.5. Objectives

In this study, soybeans were chosen as a standardized main crop and winter rye was used as the preceding cover crop on a sandy, a loam and a clay soil. The main research objectives were:

1) to study the timing of rye killing in a rye/soybean system, where the rye is planted in the fall, chemically killed and mowed in the spring, and soybeans are no-tilled through the rye mulch;

2) to investigate the effect of a rye mulch on soybean growth and yield;

3) to measure the effect of rye mulch on soil water and soil temperature.

4) to model the effect of a rye mulch on soybean growth under various weather scenarios.

Section 2 - FIELD EXPERIMENTS

2.1. Material and Methods

2.1.1. Experimental Design

A preliminary experiment was conducted at the Agriculture Canada Research Station in Delhi (42°08' N, 80°30' W, 232 m) during 1988. Soybeans were grown under two treatments (1-no-tillage, rye mulch, 2-conventional tillage, no mulch), in a randomized complete block design with eight replicates and plots 5 m wide and 7 m long. In 1989 and 1990, the experiment was continued at Delhi and expanded to the University of Guelph Research Station in Woodstock (43°08' N, 80°46' W, 282 m) and the Hedley Seed Enterprises farm in Canfield (42°59' N, 79°40' W, 212 m). Three treatments were evaluated (1-no-tillage, rye killed early; 2-no-tillage, rye killed late; 3-conventional tillage, no mulch) during those years. The experimental design was a randomized complete block with four replicates and plot size 10 m by 12 m.

The soil types at the experimental sites were a Fox sand, Guelph loam and a Haldimand clay, respectively, for Delhi, Woodstock and Canfield. Particle size characterization and fertility levels for the sites and years studied are shown in Table 2.1.

2.1.2. Agronomic Aspects

2.1.2.1. Establishment of Cover Crop

The rye cover crop was established during the fall previous to the study year, using local seed (Canada no. 1, Danko) at a seeding rate of 95 kg/ha and row spacing of 18 cm at Woodstock and 20 cm at Delhi and Canfield. A new field within the farms was used each year. During the summer previous to cover crop planting, the experimental fields had been cropped with rye, soybeans and clover at Delhi, Woodstock and Canfield, respectively. Rye seedbed preparation normally involved disking and cultivating. However, it was not possible to work the soil at Woodstock and at Canfield during the fall of 1988, due to adverse weather conditions. Rye was then planted no-till through the clover and soybean residue at

Table 2.1 - Soil characterization for the experimental sites.

Location	Year	%Clay	%Silt	%Org. mt.	pH[$]	P ppm	K ppm	Mg ppm	Texture[*]
Delhi	1988	4.5	9.0	1.2	6.0	-	-	-	S
	1989	-	-	-	6.1	57	138	125	S
	1990	3.7	9.4	1.1	6.5	52	71	99	S
Woodstock	1989	12.5	34.5	3.3	6.8	18	110	169	fSL
	1990	17.4	47.9	4.4	7.2	24	75	216	L
Canfield	1989	42.3	46.5	4.3	5.4	-	-	-	SiC
	1990	43.7	46.2	4.3	6.0	17	150	555	SiC

[$] $CaCl_2$
[*] S=sand, fSL=fine silt loam, L=loam, SiC=silty clay.

Table 2.2 - Dates of major management practices for the locations and growing seasons studied.

Location	Year	Cover crop planting	Plowing/disking	Killing date		Soybean planting
				early	late	
Delhi	1987/88	Oct 1	May 8	-	May 22	May 26
	1988/89	Sep 27	May 4	May 11	May 19	May 24
	1989/90	Sep 20	May 2	May 3	May 14	May 23
Woodstock	1988/89	Oct 14	Oct 20	May 17	May 24	May 29
	1989/90	Sep 22	Sep 22	May 8	May 15	Jun 1
Canfield	1988/89	Oct 6	Nov 1	May 18	May 30	-
	1989/90	Sep 28	May 31	-	May 24	Jun 1

those sites in 1988. This may have influenced the results obtained the following spring and summer, since the effect of the rye residue could not be isolated from the effect of the residue remaining from the previous crop. During the winter of 1989/1990 the rye cover crop was extensively damaged by winter kill in Canfield. The experiment was then moved to a winter wheat field (variety Augusta, seeding rate 164 kg/ha), which presented a good

stand in the spring.

Soil pH was corrected to 6.1 by broadcasting lime three weeks prior to rye planting in 1988 at Delhi. Fertilizer was applied at cover crop planting date in Canfield at a rate of 195.2 kg/ha (8-32-16) in 1988 and 84 kg P_2O_5/ha in 1990. Ammonium-nitrate was applied to the cover crop fields in Delhi at a rate of 20 kg/ha of nitrogen on April 25, 1988 and 45 kg/ha of nitrogen on April 6, 1989 and April 5, 1990. A double application of urea was performed at a rate of 40 kg/ha of nitrogen on March 25 and May 8, 1990 at Canfield. Muriate of potash and ammonium-nitrate were broadcast at a rate of 30 kg/ha of potassium and 21 kg/ha of nitrogen, respectively, at soybean planting time in Delhi 1988. No fertilizer was applied at Woodstock during any of the study years.

2.1.2.2. Establishment of Treatments in Spring

The conventional tillage treatment consisted of plowing the rye crop under in the spring, followed by cultivating prior to soybean planting at Delhi; plowing in the fall of 1988 and disking in the fall of 1989, followed by cultivating in the spring at Woodstock; plowing in the fall of 1988, raking mowed mulch off plots by hand and disking in the spring of 1990 at Canfield.

The mulched treatments were obtained by killing the cover crop with Glyphosate at 0.9 kg/ha (a.i.) on the dates listed in Table 2.2. In 1988 at Delhi, there was only one killing date, and rye mulch from surrounding fields was added to the mulched plots at a rate of 2,750 kg/ha on May 31, with the objective of simulating an extreme mulch cover situation.The early killing date was 13 and 12 days before soybean planting at Delhi and Woodstock, respectively, in 1989, and 20 and 24 days before soybean planting at Delhi and Woodstock, respectively, in 1990. The late killing date was 5 days before soybean planting at both locations in 1989, and 9 and 17 days before soybean planting at Delhi and Woodstock, respectively, in 1990. At Canfield, the mulched treatments were modified to standing mulch and mowed mulch in 1990, after killing on one single date, with the objective of studying the benefits of less ground cover (standing mulch) on the spring drying of the

poorly drained clay soil.

The killed, standing rye was mowed on the same date as soybean planting, using a sickle-bar mower at Delhi in 1988-1990, and at Woodstock and Canfield in 1990. A hay-binder was used at Woodstock and a lawn mower at Canfield in 1989. The sickle-bar mower resulted in a mulch of 10cm-high standing stubble and straw of approximately 30 cm length (early killing date) and 50 cm length (late killing date) lying on the ground in strips orientated along the rye rows. The hay-binder left 10 cm-high stubble standing and rye straw pieces of 10-20 cm length spread randomly on the ground. The lawn mower resulted in rye straw pieces 5-10 cm long, spread randomly on the soil surface.

After rye mowing, soybean rows were no-till planted 40 cm apart at a seeding rate of 84 kg/ha, 100 kg/ha and 88 kg/ha in Delhi (variety A1937), Woodstock (variety Pioneer 0877) and Canfield (variety Elgin 87) on the dates presented on Table 2.2. It was not possible to plant soybeans before the end of June 1989 in Canfield. Causes were high rainfall that occurred there (maximum of only three consecutive rain-free days in May and four consecutive rain-free days up to June 22), and the drainage characteristics of the clay soil. It was then decided to cancel the experiment in Canfield for the 1989 season, since planting in July characterized an unusual, high risk operation.

Complete weed control was achieved in Delhi by spraying the plots with Metolachlor (2.64 kg/ha) and Chloramben (2.22 kg/ha) on May 27, 1988, June 1, 1989 and Bentazon (1.08 kg/ha) and Fenoxaprop-ethyl (117 g/ha) on June 22, 1988 and June 3, 1990. Plots were sprayed with Metolachlor (1.92 kg/ha) and Linuron (1 kg/ha) in Woodstock on June 1, 1989, but weed control was only marginal in some of the plots, due to gaps in the manual spraying and due to the high weed pressure. Good weed control was obtained by the same herbicides sprayed on June 4, 1990 at Woodstock.

Soybeans were irrigated on June 21 and July 3, 1988 with 25 mm each time, due to the prolonged drought that followed soybean planting.

2.1.3. Cover Crop Measurements

Cover crop phenological observations were done on the experiment at approximately weekly intervals, except for the 1987/1988 rye growing season, when no observations were taken.

Cover crop sampling for dry matter accumulation was done four, three and two times during the spring of 1989, at Delhi, Woodstock and Canfield, respectively. Rye plants were sampled four times in the spring of 1990 at Delhi and Woodstock. The two last sampling dates in the spring at each site occurred on the early and late rye killing dates. The residue from the previous crop remaining on the soil surface in Woodstock and Canfield in the spring of 1989, was collected from 1 m^2 in each plot during the last sampling date. No cover crop plants were sampled at Delhi in 1988 and at Canfield in 1990. Rye plants were sampled from 1 m^2 of each of the plots from treatments 1 and 2. The first sampling was done in an area randomly located either at the back or the front of a 2m-wide strip along the left or the right side of each plot, depending on year and site. Successive sampling locations were then alternated between back and front, moving inwards to the middle of the plot. All sampled plants were washed, oven dried at 67 C for 72 h, and weighed.

The effect of the killing dates on the rye mulch biomass and percentage ground cover was tested using the F-value obtained through an analysis of variance. Treatment means were compared using Tukey's test for F-values significant at the 0.05 level.

2.1.4. Soybean Measurements

In 1988, only major phenological stages were registered at Delhi. The phenological stage of soybeans in each plot was registered every 2-3 days at Delhi and Woodstock in 1989 and 1990. No phenological observations were made at Canfield in 1990.

Soybean plants were sampled four and seven times from an area of 0.8 m^2 per plot, respectively, during the 1989 and 1990 growing seasons at Delhi and Woodstock. The areas sampled were a 2m-wide strip along the side of the plot, opposite to the location where rye plants had been sampled in the spring. Sampling was done

following the same scheme of alternating location between front and back of the plot, as was used for the rye sampling.

Shoots were sampled by cutting the plants from two one-meter sections of row at the soil surface level, then counted and washed. Roots and nodules were sampled by digging the plants in one-meter row sub-sample down to 30 cm, twice at Delhi and Woodstock in 1989 and 1990 and once at Canfield in 1990. Roots were separated from the shoot, washed and nodules separated for counting. Leaves from one-meter row sub-samples were separated from the petioles and stem twice and four times in Woodstock and Delhi, respectively, during 1989 and 1990. Total leaf area was determined using a LICOR area meter. Pods were separated from the stem, and pods, flowers and buds in one-meter row sub-samples were counted four times during the 1990 season at Delhi and Woodstock. All plants and plant parts were dried at 67 C for 72 h and weighed.

At each plant sampling date in 1989 and 1990, the rye residue covering 1 m^2 was scraped off the soil surface, washed, oven dried at 67 C for 72 h and weighed. In 1988, rye mulch was sampled once at Delhi. The percentage ground covered by residue was also measured in each plot once in 1989 and twice in 1990, using the line-transect method as described by Laflen at al. (1981).

Ten plants were randomly selected from each plot at physiological maturity in 1989, and on harvest date in 1988-1990. Plants collected at physiological maturity were washed and the leaves were separated from petioles. Total leaf area from each sample was then determined using a LICOR area meter. Plant parts were dried at 67 C for 72 h and weighed. Plants sampled on the harvest date were separated into pods, seeds, stem and branches. The number of nodes, branches, pods and seeds was calculated for each plant in a sample. The pod, seed and stem (no petioles) dry weight for each sample was obtained.

In addition to the individual plant samples described above, an area of 4.8 m^2 was hand-harvested on October 19, 1988, and six rows of 10 m length in the center of each plot were harvested by combine on October 11, 1989 and October 16, 1990 at Delhi. Four 6-

m rows were hand-harvested from the center of each plot in Woodstock on October 12, 1989 and October 24, 1990. Four 4-m rows were hand-harvested on November 11, 1990 at Canfield. Observations made on the harvest date at each location and year for all plots included yield, height of lowest pod, lodging, and canopy height.

Soybean seed moisture at harvest was measured using a electronic moisture tester (John Dickie International GAC-2). Seeds were dried at 40 C for 72 h and subsequently cleaned, weighed and tested for moisture. Yields were adjusted to 14% moisture.

Treatment effects on all measured variables were tested through an analysis of variance, rejecting the null hypothesis if the probability of the F-value was ≤ 0.05. Variable means were then compared using a Tukey test at the 0.05 level of probability.

2.1.5. Weather Measurements

Automated weather stations monitored weather variables at all sites from April to November during the years studied. The stations were located within 10 m of the experimental plots in an area free of obstacles. Data obtained by the OMAF weather station in Woodstock and by the AES weather station in Delhi (about 500 m from the experimental sites) are available for the periods from December to March. The weather variables monitored were:

a) wind speed and direction (R.M. Young wind monitor)
b) rainfall (Rimco tipping bucket raingauge)
c) global solar radiation (LI200SZ LI-COR pyranometer)
d) air temperature and relative humidity (Rotronic MP-100 probe)

The humidity-temperature probe was shielded by a Gill multi-plate radiation shield. All variables were measured every minute and averaged over one hour, and the average recorded by a datalogger system (CR21X Campbell Scientific).

2.1.6. Soil Temperature Measurements

After soybean planting, thermocouples were inserted horizontally into the soil at depths 5, 10, 15 and 30 cm, perpendicularly to the soybean rows. The Cu-Constantan thermocouples had been inserted in a 20 cm long copper tube filled

with epoxy resin, for purposes of waterproofing and spatial averaging, following a procedure described by G. W. Thurtell (pers. comm.). Thus, the temperature values obtained were horizontal averages over 20 cm, covering 10 cm row and 10 cm interrow spaces, at each depth considered. The thermocouples were connected to the datalogger system and temperature values were recorded over the same intervals described for the weather station sensors.

Hourly soil temperature values were analyzed for their frequency distribution for each month following planting of soybeans.

2.1.7. Soil Water Measurements

Volumetric soil water content was measured with a Tectronix Cable Tester (model 1502B) using the Time Domain Reflectometry Technique as described by Topp (1987). Rods were inserted vertically into the soil to obtain volumetric water percentages over the length of the rods.

Soil water measurements started after soybean planting in 1988 with vertically placed pairs of 30 and 60 cm-long rods. In each plot of four plots per treatment, four replications at each depth were measured, two positioned between rows and two in the rows of the soybean crop.

Soil water content measurements were restarted in the spring of 1989. Rods were inserted vertically to a depth of 10, 30 and 60cm. In each plot, four, two and two replications were obtained for the 0-10 cm, 0-30 cm and 0-60 cm layers, respectively. Half of those rods were positioned in the crop rows and the other half between rows.

Measurements were carried out for rye plots and plowed plots during April and May, at about 6-day intervals in 1989 and 3-day intervals in 1990. After soybean planting, until physiological maturity, measurements were done every 2-3 days. Measurements performed in the spring and summer of 1990 followed the same procedure as described above for 1989.

Values of soil water measured for the surface layer (0-30 cm in 1988, and 0-10cm for 1989-1990) at Delhi and Woodstock were

separated into drying periods following a rainfall event and a drying curve was fitted to the data. The methodology used for the analysis is described by Zhai at al. (1990). The regression equation used was:

$$\theta_{i,t}=\theta_{i,0}\exp(-K_i t)$$

where $\theta_{i,t}$ is volumetric soil water (%) at position i and time t, $\theta_{i,0}$ is volumetric soil water (%) at position i and time t=0, K_i is drying coefficient at position i (d^{-1}), t is time in days after start of drying period.

Drying coefficients fitted to each measurement position (row and interrow) in each plot where then averaged and tested for treatment and position effects using an analysis of variance. When treatment or position effects were significant at the 0.05 level, means were compared using Tukey's test. This methodology was not applied to data obtained at Canfield, since no well-defined drying period could be selected from the measurements.

Soil water measurements in all layers for the treatments studied were compared, using the same statistical tests described above, on dates corresponding to major phenological events such as emergence, flowering and start of pod filling.

2.2. Results and Discussion

2.2.1. Cover Crop Measurements

2.2.1.1. Rye Growth

The rye cover crop at Delhi in November of 1988 and 1989, and at Woodstock in 1989 was well established, with rye plants having 2-3 tillers. In 1988 at Woodstock and Canfield, plants had only 2 and 3 leaves unfolded by the end of November due to the later planting date (respectively October 14 and 6, as compared to September 27 at Delhi) and to the cooler weather conditions that prevailed after planting.

The dry matter accumulation curves (Figure 2.1) show that the growth rate was similar for rye grown at Woodstock and at Delhi

in both years. The rye growth rate was approximately 75 kg/(ha.day), during the three weeks before killing in 1989. This resulted in an increase of 36% and 106% in rye dry matter from the early to the late killing date, respectively for Delhi and Woodstock (Table 2.3). But, because of the retarded rye growth during the fall of 1988 at Woodstock, the dry matter values at the time of killing were considerably lower than the values measured at Delhi. The fact that no nitrogen fertilizer was applied to the rye grown in Woodstock is not considered to be the cause of the difference in growth, since the experimental site had been cropped with soybeans during the previous summer.

At Canfield in 1989, rye growth was very slow (Figure 2.1) probably related to the extremely wet weather conditions that occurred there in the spring.

In the spring of 1990 the rye growth rate was approximately 150 kg/(ha.day) at Delhi and 175 kg/(ha.day) at Woodstock (Figure 2.1B) resulting in final dry matter values 1.5 times larger than 1989 values at Delhi, and 4-6 times larger than 1989 values at Woodstock. This was due to a one week period of exceptionally good growing weather at the end of April 1990 (Figure A.3 and A.5) with maximum air temperatures around 25 C. Better growing conditions at Woodstock, such as higher soil water holding capacity and fertility, explain the much larger dry matter values obtained there in relation to Delhi in 1990.

The early and late killing dates occurred, respectively, at the second node detectable and flag leaf extended stage of rye in 1989, and flag leaf extended and boots swollen in 1990 (Table 2.4) for both locations. For the control treatment at Delhi, rye was plowed under when it was at the first node detectable in 1989 and second node detectable in 1990. The more advanced phenological stages at the killing times in 1990 were also related to the warmer weather in the spring.

2.2.1.2. Rye Mulch

For Delhi and Woodstock during both years the time between early and late killing dates resulted in significantly

Table 2.3 - Cover crop and previous crop dry matter and percentage ground cover at soybean planting time.

Location	Year	Dry matter (kg/ha)			% Ground cover	
		Early	Late	Previous crop[$]	Early	Late
Delhi	1988	-	4550[*]	-	-	
	1989	1534 a[#]	2093 b	-	32 a	61 b
	1990	2250 a	3478 b	-	84 a	91 a
Woodstock	1989	568 a	1172 b	1743	57 a	76 b
	1990	3459 a	4776 b	-	73 a	86 a
Canfield	1989	469 a	523 a	2860	93 a	94 a
	1990	3023 a	2390 a	-	-	89

[$] soybeans at Woodstock and clover at Canfield.
[*] 2750 kg/ha added manually to plots.
[#] Not significant differences (P=0.05) between early and late treatment means is shown by the same letters in a row.

Table 2.4 - Date of occurrence of major phenological stages of rye at the sites studied.

Stage (Zadoks scale)	Delhi		Woodstock	
	1988/89	1989/90	1988/89	1989/90
Emergence (10)	Oct 3	-	Nov 1	Oct 5
One tiller (21)	Nov 7	Oct 19	-	Oct 26
First node (30)	May 3	Apr 30	-	Apr 30
Second node (32)	May 11	May 2	May 17	May 8
Flag leaf (41)	May 19	May 2	May 24	May 8
Boots swollen (45)	-	May 11	-	May 14

higher residue biomass accumulated for the later date (Table 2.3). The rye residue on the soil surface for the early and late killing dates at Woodstock in 1989 was 25% and 40%, respectively, of the total amount of residue present, the remaining being previous crop residue (soybeans).

Significant accumulation of rye dry matter from an early

to a late killing date (2-3 weeks apart) was also observed in another study conducted during three years (Munawar et al., 1990). Average dry matter accumulated was 1560 kg/ha in the 2-3 week period. Moschler et al. (1967) observed rye dry matter accumulation of 2225 kg/ha in 17 days following an early rye killing. Wagger (1989) measured a 2-year average of 39% in rye dry matter increase in a 2-week time period.

In Bond and Willis' (1970) laboratory experiment, rye mulch dry matter values comparable to the amounts obtained in 1989 (Table 2.3), reduced first stage evaporation by 50% or less, while the ones comparable to the 1990 amounts were more effective, presenting reductions between 60 to 80%. Section 2.2.3. will describe the observed effects on soil moisture at the studied sites.

At Canfield, reduced rye growth resulted in no significant difference between mulch biomass at the two killing dates in 1989 (Table 2.3), while in 1990, wheat under the standing and mowed treatments had been killed on the same date.

An early spring fertilization proved helpful to obtain adequate amounts of rye mulch biomass at the sandy soil site (Delhi), (C.J. Swanton, pers. comm.).

The percentage ground cover associated with the rye residue present at soybean planting ranged from 32% (early-kill at Delhi in 1989) to 91% (late-kill at Delhi in 1990) (Table 2.3). The timing of rye killing had a significant effect on percentage ground cover only during 1989 at both locations. The relation between rye mulch dry matter and percentage ground cover obtained is presented in Figure 2.2. It shows that dry matter values above 2000 kg/ha cover over 80% of the soil surface in the system studied. Therefore, significant differences in rye mulch biomass over 2000 kg/ha did not correspond to significant differences in percentage cover.

The change in dry matter of rye residue sampled during the 1989 and 1990 growing seasons is shown in Figure 2.3. By the middle of June 1989 (day 166), an average of 17 and 40% of the

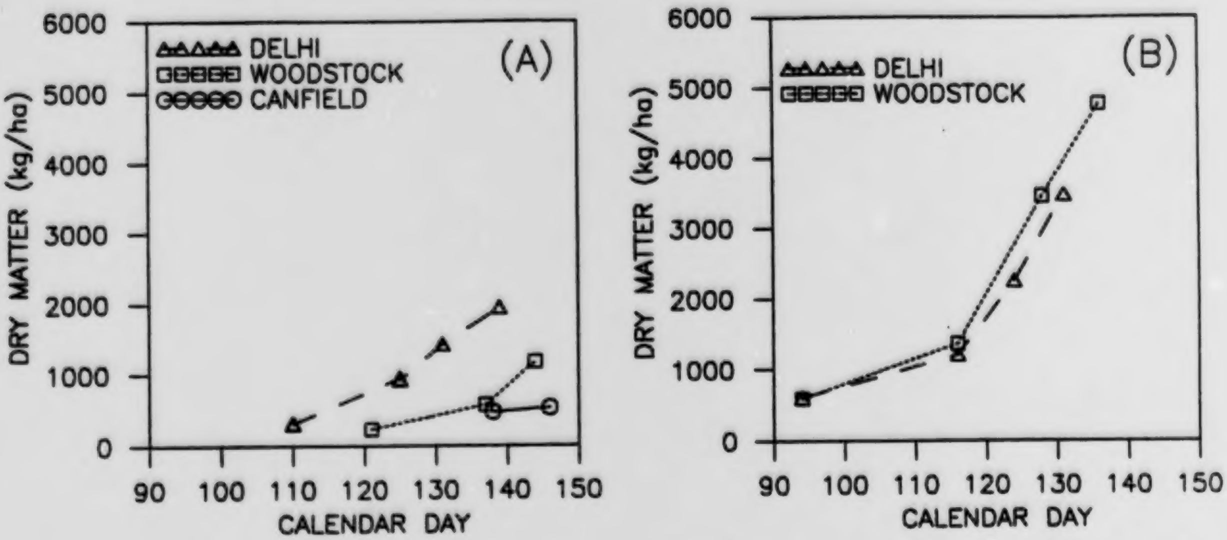

Figure 2.1 - Rye dry matter accumulation in the spring of (A) 1989 and (B) 1990 at the locations studied. The last two sampling dates in both years refer to early and late killing dates, respectively.

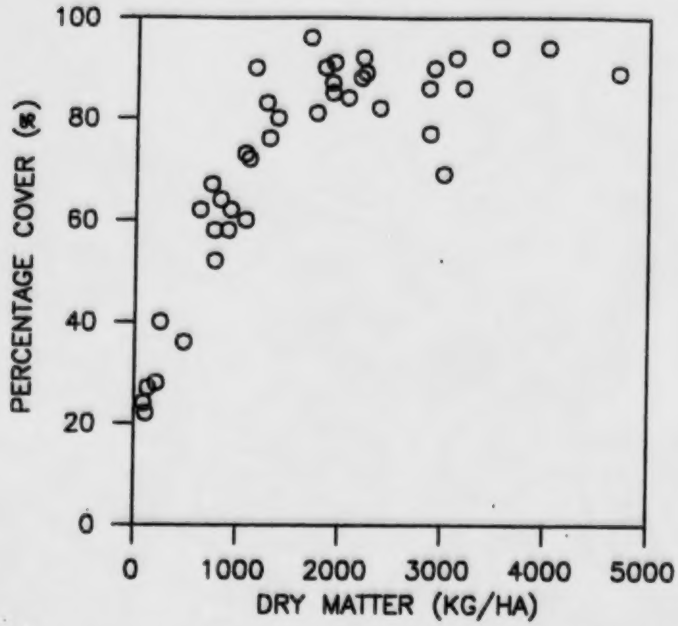

Figure 2.2 - Relationship between rye mulch dry matter (kg/ha) and percentage ground covered by rye mulch. Data points shown were obtained at Woodstock in 1990 and at Delhi in 1989 and 1990.

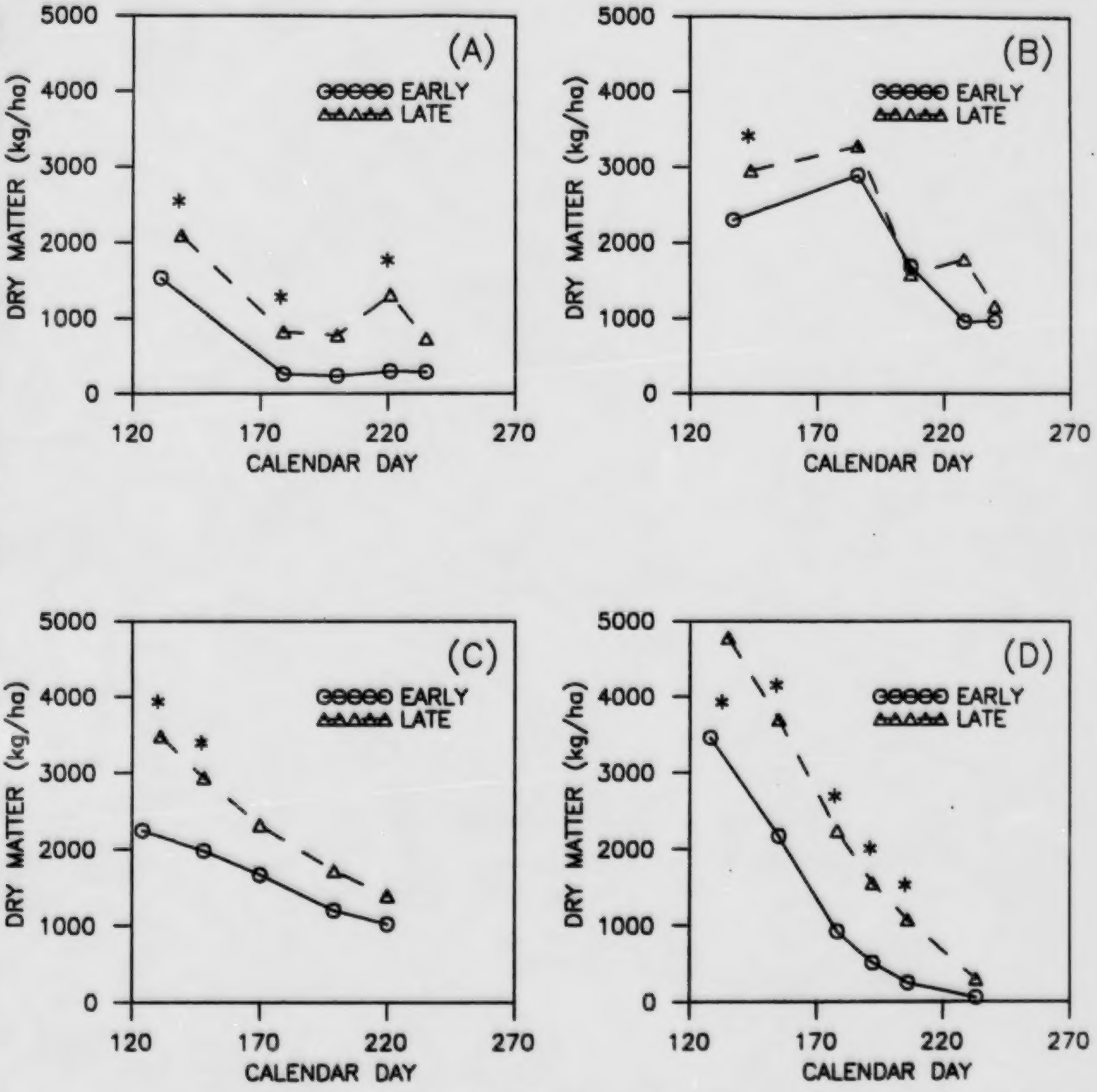

Figure 2.3 - Rye mulch dry matter decrease as a function of time after killing for (A) Delhi 1989, (B) Woodstock 1989, (C) Delhi 1990 and (D) Woodstock 1990.
*** indicates means significantly different at the 0.05 level.**

initial amount was left on the soil surface at Delhi for the early and late killing treatment, respectively. In 1990, an average of 70 and 40% of the initial mulch biomass was present on the soil surface by the middle of June at Delhi and Woodstock, respectively. These results show that even large amounts of cover crop residues present at soybean planting time do not assure that substantial soil water will be conserved during later stages, such as flowering or pod filling.

Substantial wheat residue losses were also monitored by Stott et al. (1990) over fall, winter and spring. On plots seeded with a no-till drill, spring crop residue losses ranged from 81 to 88% by harvest time.

The slightly different pattern of mulch decrease at Woodstock in 1989 (Figure 2.3B) is probably due to the presence of withered soybean residue, which would not have followed the same pattern as rye residue decomposition.

As already mentioned, the amount of residue at killing time (first observation on Figure 2.3) was significantly different at all location-years. That significant difference was maintained for most of the growing season at Woodstock in 1990, but disappeared after the second sampling date at Delhi.

2.2.1.3. Summary

Significantly larger rye mulch dry matter was obtained at the later rye killing date, during all experiments. Percentage ground covered by the rye mulch was significantly larger for the late killing date in the year less favourable to rye growth (1989). No significant increase in percent ground cover was achieved once rye biomass exceeded 2000 kg/ha.

An early spring nitrogen fertilization was helpful to obtain adequate amounts of rye mulch biomass at the sandy soil site. A substantial decrease in rye mulch dry matter was observed at all locations during the growing season, with little mulch left by the end of June of the study years. Because of this decrease, the effects of mulches on crop growth will be mainly confined to the first third of the growing season.

2.2.2. Soybean Measurements

2.2.2.1. Soybean Phenology

The phenological development of soybean plants for the three treatments studied is summarized in Table 2.5 and 2.6. The date of occurrence of some phenological stages for the three treatments differed by a maximum of two days in Delhi 1990 (Table 2.5) and three days in Woodstock 1989 (Table 2.6).

In 1990 at Delhi, bean emergence, start of pod filling, physiological maturity and harvest maturity occurred significantly earlier for the no-mulch treatment as compared to the mulched treatment. This was mainly related to a slow start to soybean growth observed in the mulched plots, especially the late-kill treatment due to a planting problem. The higher amount of residue was not handled properly by the 10" ripple coulter of the no-till unit planter used, which pushed the residue into the seed furrow instead of cutting through it. As a result, seeds were not in good contact with the soil and emergence and early growth were delayed. Seed-soil contact problems due to pressing of rye into the seed furrow by the planter were also observed by Eckert (1988), causing stand and yield reduction.

In experiments conducted in Virginia, Hovermale et al. (1979) concluded that although mulch rates did not affect final stand of soybeans significantly, there was a tendency toward fewer plants in the heaviest mulch rate. They pointed out that under moist soil conditions the fluted coulter tended to press straw into the soil, rather than cutting through it, and suggested using a straight coulter to overcome the problem.

The same problem did not happen at Woodstock in 1990, even though the rye residue amount was higher than at Delhi 1990, since a different planter (no-till drill) was used. On the contrary, there was a tendency of later emergence in the no-mulch treatment at Woodstock (significant difference in 1989), probably due to a deeper placement of seeds, since all plots were planted at the same time using the same planter, and the soil was obviously

Table 2.5 - Date of occurrence of major phenological stages of soybeans at Delhi for the years and treatments studied.

Years	1989			1990		
	Treatments					
Stage (Fehr et al. 1971)	Early	Late	No mulch	Early	Late	No mulch
Emergence (V0)	Jun 1	Jun 1	Jun 1	Jun 3 b	Jun 4 c	Jun 2 a
First flower (R1)	Jul 8	Jul 8	Jul 8	Jul 11	Jul 11	Jul 11
Pods 0.5 cm (R3)	Jul 22	Jul 22	Jul 22	Jul 26	Jul 27	Jul 26
Pod filling (R5)	Aug 3	Aug 3	Aug 2	Aug 9 b	Aug 8 b	Aug 7 a
Phys. maturity (R7)	Sep 13	Sep 13	Sep 12	Sep 15 b	Sep 15 b	Sep 13 a
Harvest maturity (R8)	Sep 26	Sep 26	Sep 25	Oct 2 b	Oct 2 b	Sep 30 a

Table 2.6 - Date of occurrence of major phenological stages of soybeans at Woodstock for the years and treatments studied.

Years	1989			1990		
	Treatments					
Stage (Fehr et al. 1971)	Early	Late	No mulch	Early	Late	No mulch
Emergence (V0)	Jun 6 b	Jun 5 a	Jun 7 c	Jun 12	Jun 12	Jun 13
First flower (R1)	Jul 14	Jul 15	Jul 13	Jul 20	Jul 20	Jul 20
Pods 0.5 cm (R3)	Jul 21	Jul 21	Jul 21	Jul 30	Jul 30	Jul 31
Pod filling (R5)	Aug 1	Jul 31	Jul 31	Aug 15	Aug 15	Aug 15
Phys. maturity (R7)	Sep 9 b	Sep 10b	Sep 8 a	Sep 15	Sep 15	Sep 16
Harvest maturity (R8)	Sep 24	Sep 23	Sep 21	Sep 30	Sep 30	Oct 1

less dense in the just-cultivated no-mulch plots. A significant difference in physiological maturity was observed among treatments with the no mulch treatment maturing earlier than the mulch treatments in 1989 at Woodstock. The harvest maturity at Woodstock in 1989 was affected by treatments but only at the 0.10 level.

2.2.2.2. Soybean Growth

The soybean canopy dry matter accumulation during the growing season can be observed in Figure 2.4. During 1989 (Figure 2.4A and 2.4B) no significant differences were observed among treatments at both locations. The planting problem at Delhi 1990, mentioned above, resulted in significantly lower plant population for the late-kill treatment, with 20 plants/m^2 compared to 30 plants/m^2 for the other two treatments. As a result, the first three sampling dates showed significantly lower canopy dry matter for the late killing treatment. But, subsequent sampling did not show significant differences among treatments, indicating that the lower population of soybean plants produced larger amounts of canopy dry matter per plant, offsetting the smaller population values. When comparing 1989 and 1990 maximum canopy dry matter values it becomes evident soybean growth was greater during 1990 at both locations. Adequate rainfall during 1990 favoured soybean growth.

Webber III et al. (1987) found that soybeans grown with no tillage in Missouri grew and matured more slowly than when grown under conventional tillage. At the R1 growth stage (flowering) soybeans grown under conventional tillage had 22% greater vegetative dry weight than those grown under no-tillage, but final yields were greater for no-tillage. Deibert and Utter (1989) found soybean dry matter at the R1 growth stage was not significantly influenced by tillage treatment.

Slight yellowing of the soybean leaves was observed for the mulched treatments at Delhi in 1988 and 1990, and at Woodstock in 1990, during a 2-3 weeks at the end of June and beginning of July. This could have been caused by organic compounds released by the decomposing mulch, but it disappeared before mid-July and it

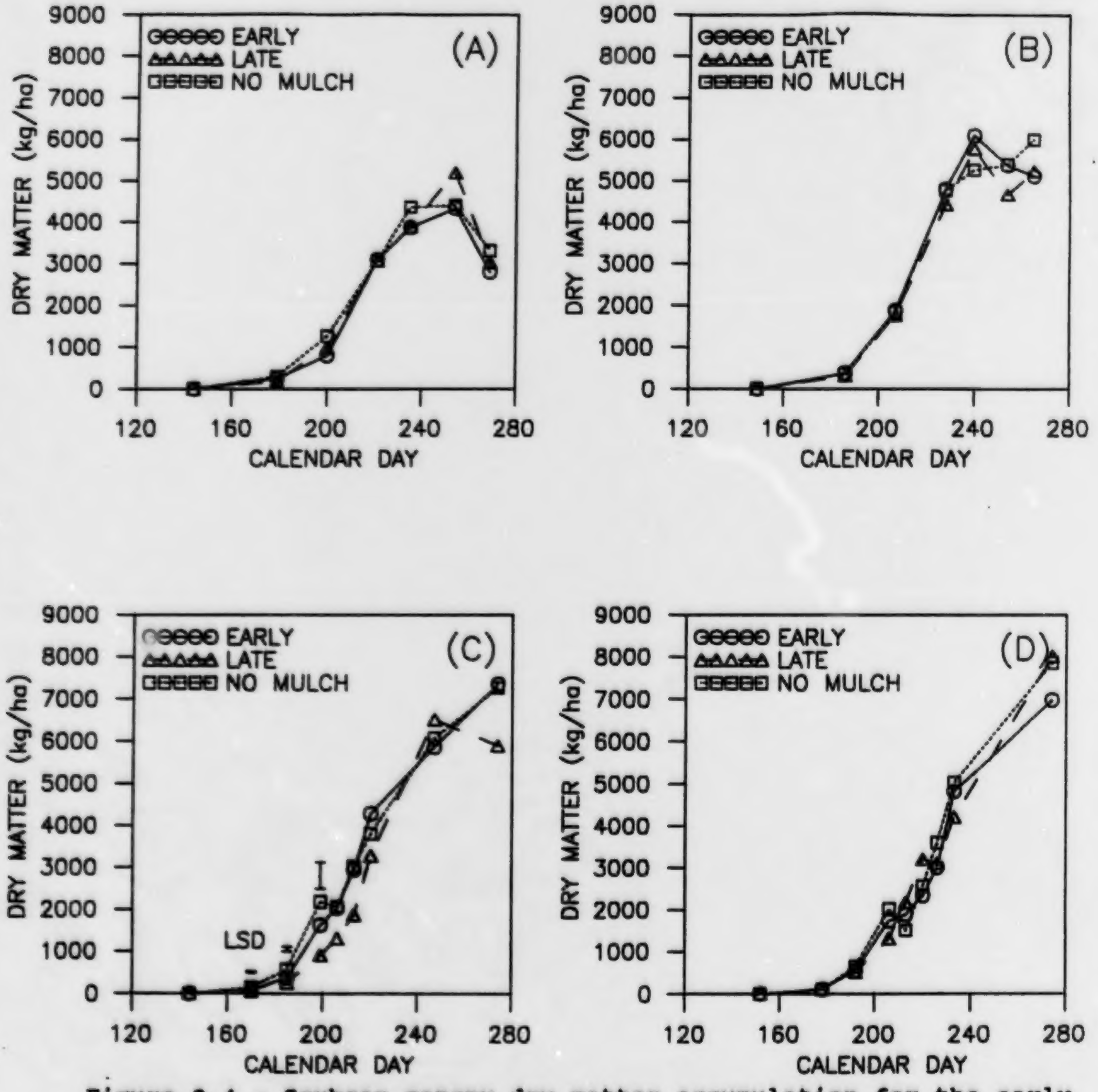

Figure 2.4 - Soybean canopy dry matter accumulation for the early and late killing, and no-mulch treatments at (A) Delhi 1989, (B) Woodstock 1989, (C) Delhi 1990 and (D) Woodstock 1990. LSD bars indicate means significantly different at the 0.05 level on certain sampling dates.

did not affect soybean growth or yield.

Change in leaf area index and leaf dry matter during the growing season are presented on Figure 2.5 and 2.6, respectively. Significant differences were observed at Delhi in 1990 (Figure 2.5C and 2.6C) with the late killing date presenting lower mean LAI and leaf dry matter on most sampling dates. LAI was significantly higher for the no-mulch treatment on the last sampling date at Woodstock 1989.

Stem dry matter measured in 1990 at Woodstock and Delhi can be observed in Figure 2.7. The late killing treatment at Delhi presented significantly lower means, again associated with the delay in emergence.

But, although stem and leaf dry matter accumulation for the late killing date at Delhi 1990 were depressed, no significant effect was observed on pod dry matter accumulation on an area basis (Figure 2.8A). Counts of flowers and pods (Figure 2.9) revealed that the late killing date had significantly higher numbers of pods and flowers than the no-mulch treatment on some sampling dates. No significant treatment effect was detected at Woodstock.

The results of soybean nodule counting and nodule dry matter are summarized in Table 2.7 and Table 2.8. Significant differences among treatments means were obtained at Canfield, with the no mulch treatment having a larger number of nodules and weight of nodules per plant. For the other location-years no statistically significant differences were detected at the 0.05 level, but the mulch treatments had consistently higher number of nodules per plant, significant at the 0.10 level on the first sampling date in 1989 and 1990 at Delhi. The second sampling date showed an opposite result with the no mulch treatment having a higher number of nodules per plant at Woodstock in 1990. Nodule dry matter per plant followed the same tendency of larger means for the mulch treatments, with significantly higher means being observed at Delhi in 1989.

Sinclair et al. (1987) observed no significant differences in the root plus nodule biomass due to various

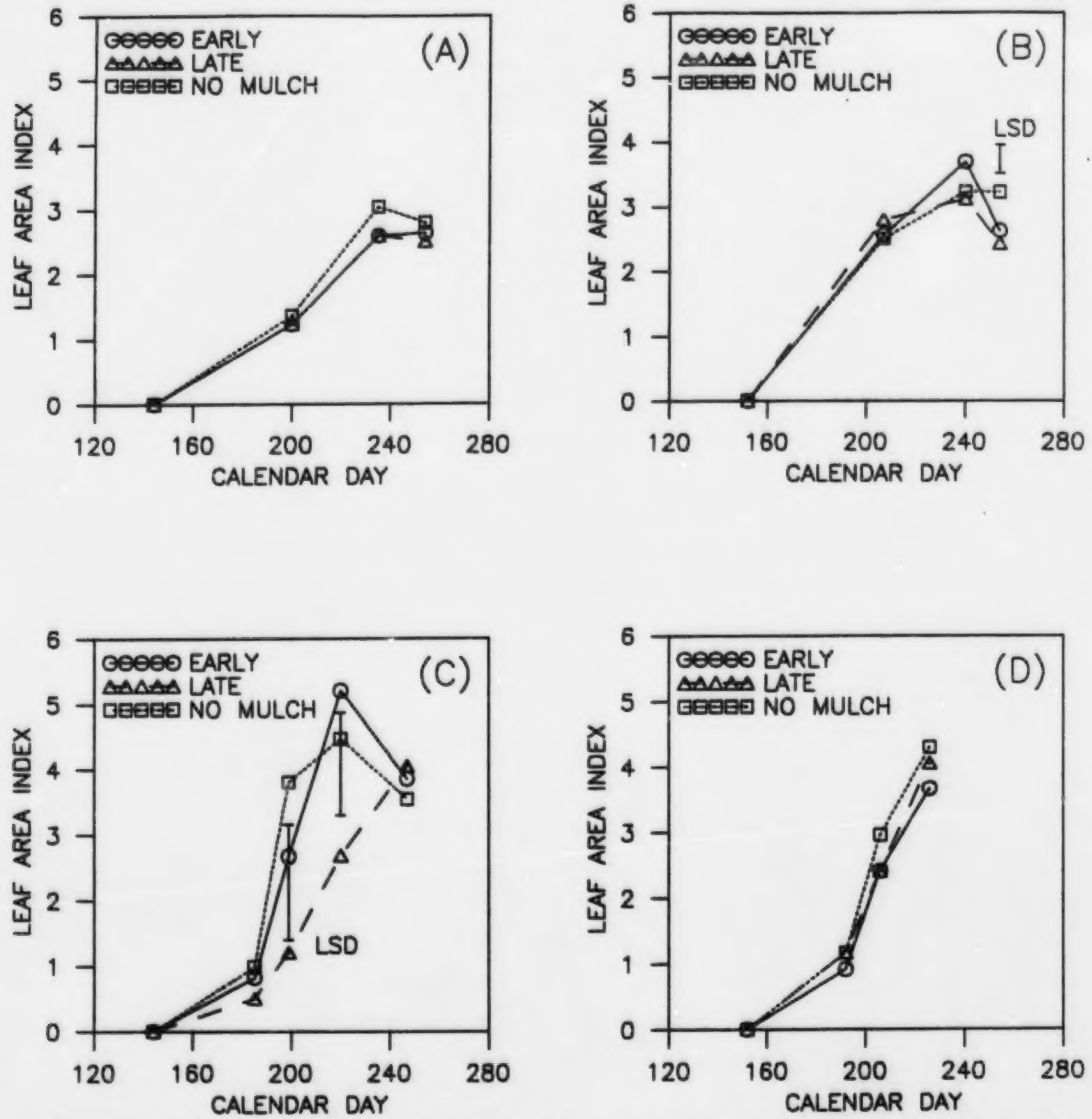

Figure 2.5 - Soybean leaf area index change over time for the early and late killing, and no-mulch treatments at (A) Delhi 1989, (B) Woodstock 1989, (C) Delhi 1990 and (D) Woodstock 1990. LSD bars indicate means significantly different at the 0.05 level on certain sampling dates.

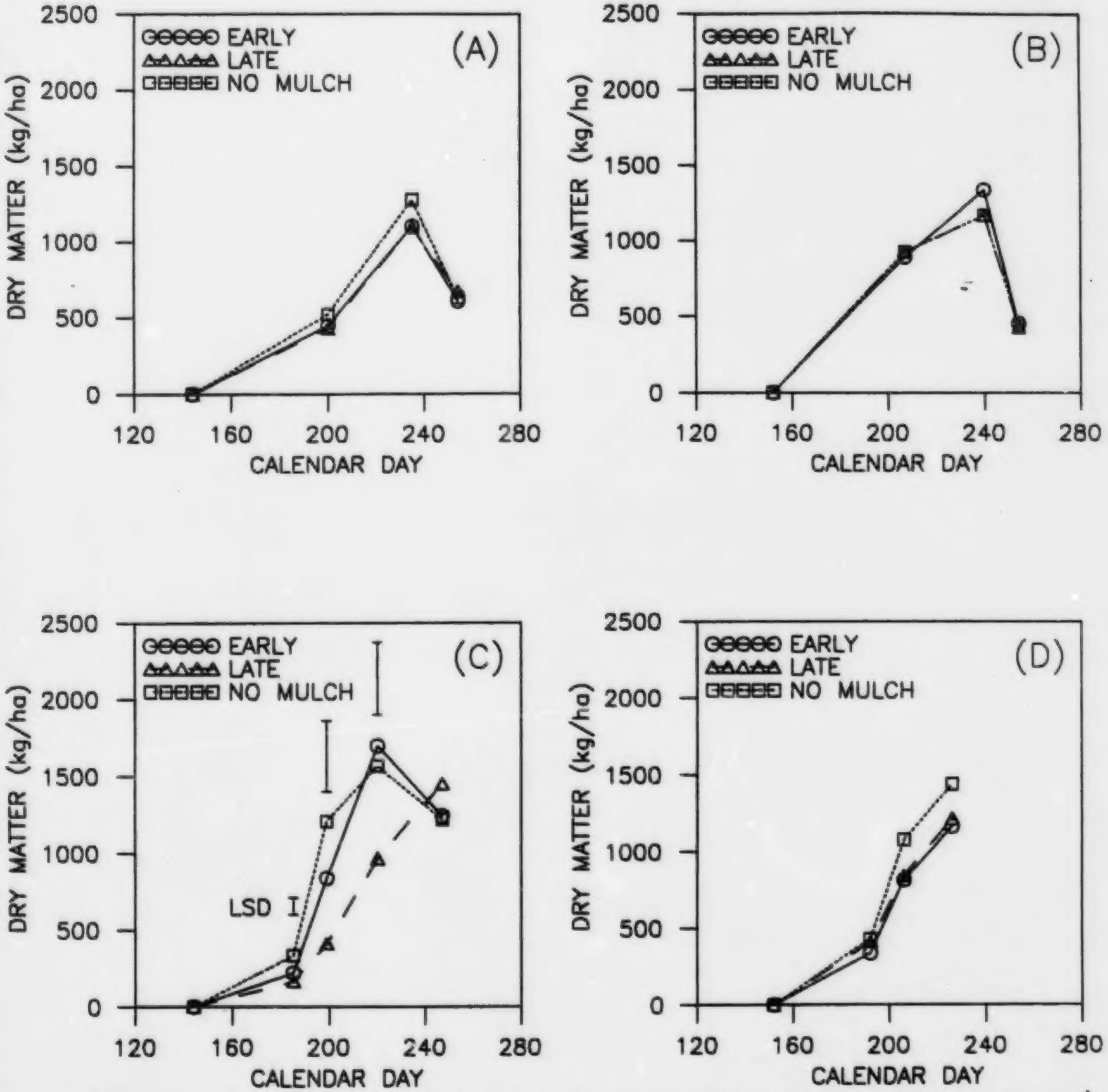

Figure 2.6 - Soybean leaf dry matter accumulation for the early and late killing, and no-mulch treatments at (A) Delhi 1989, (B) Woodstock 1989, (C) Delhi 1990 and (D) Woodstock 1990. LSD bars indicate means significantly different at the 0.05 level on certain sampling dates.

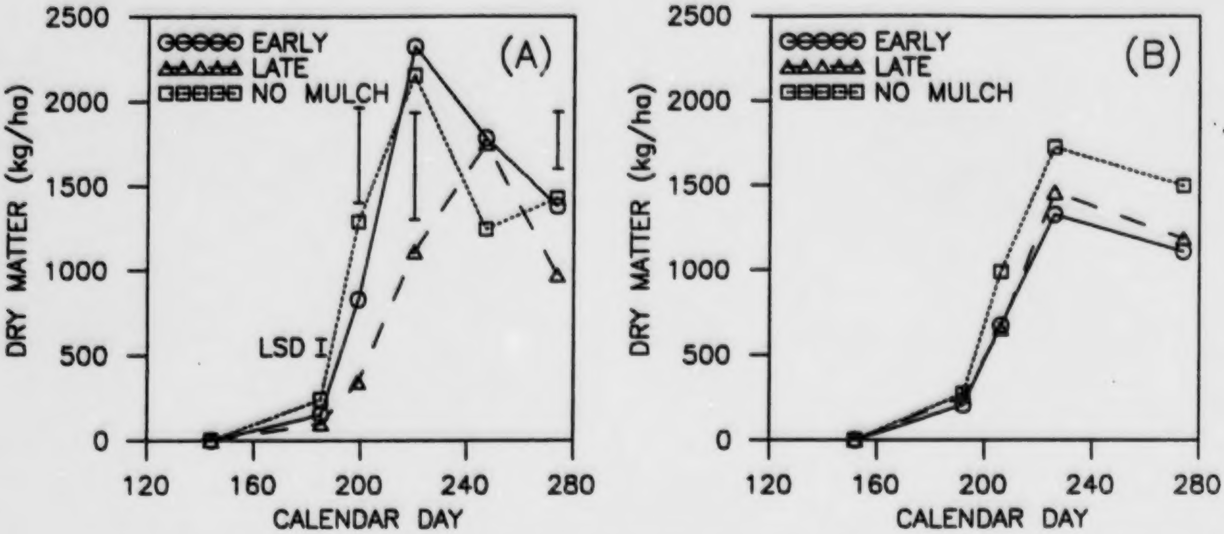

Figure 2.7 - Soybean stem dry matter accumulation for the early and late killing, and no-mulch treatments at (A) Delhi 1990 and (B) Woodstock 1990. LSD bars indicate means significantly different at the 0.05 level on certain sampling dates.

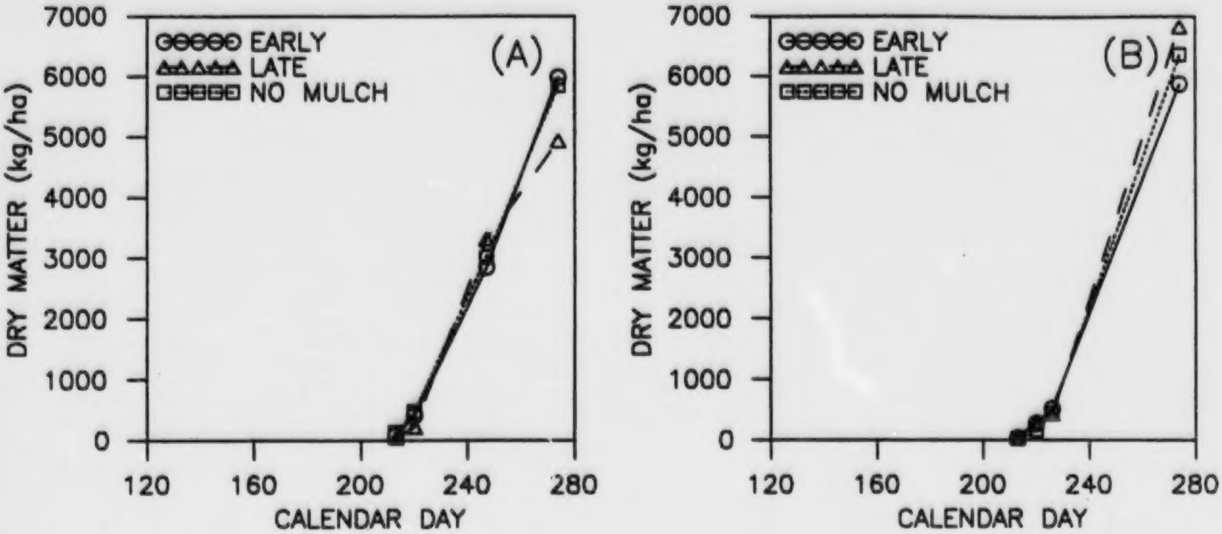

Figure 2.8 - Soybean pod dry matter accumulation for the early and late killing, and no-mulch treatments at (A) Delhi 1990 and (B) Woodstock 1990. No significance was detected among means at the 0.05 level.

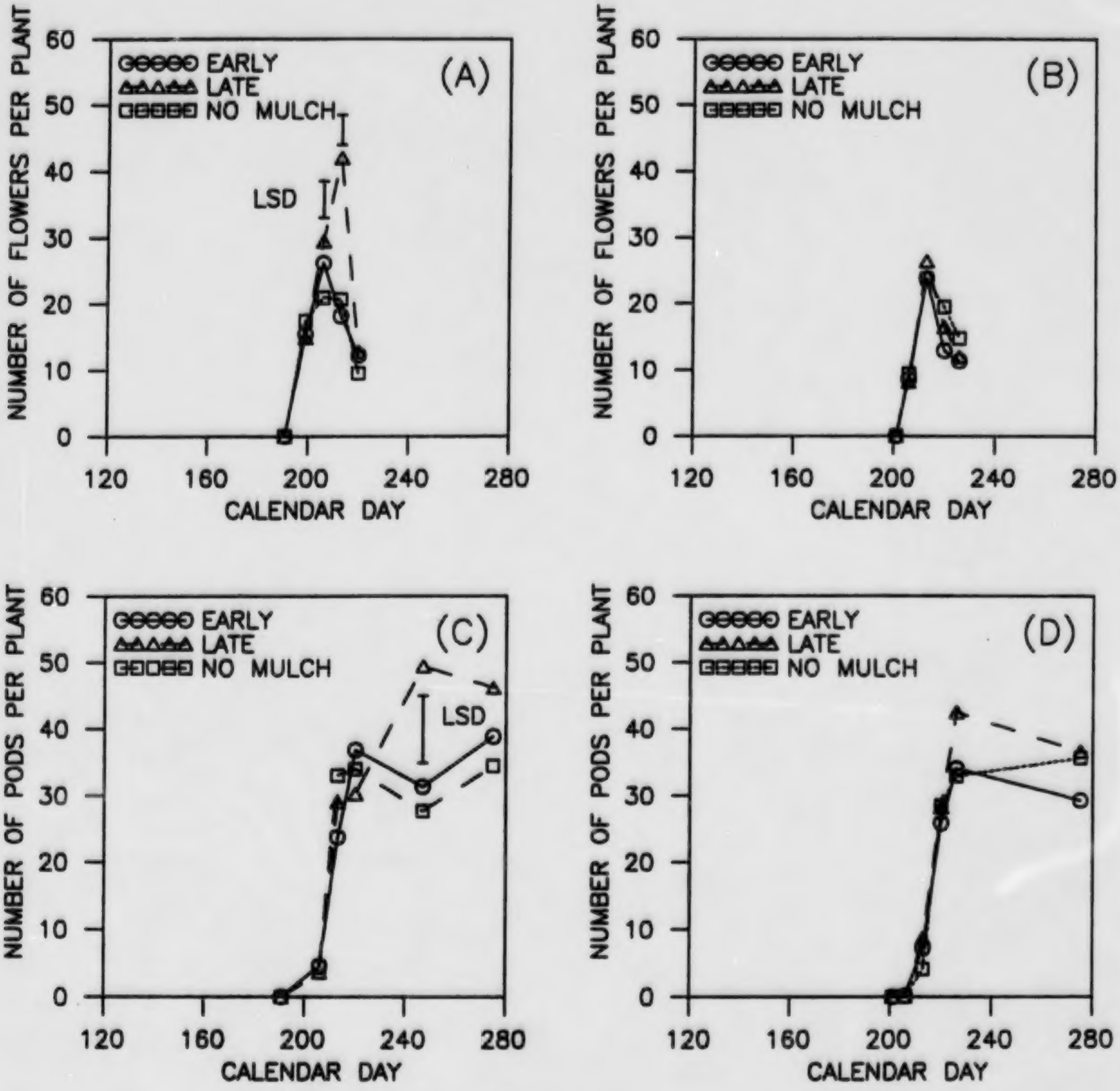

Figure 2.9 - Number of soybean flowers per plant counted in 1990 at (A) Delhi and (B) Woodstock, and number of pods per plant counted in 1990 at (C) Delhi and (D) Woodstock for the early and late killing, and no-mulch treatments. LSD bars indicate means significantly different at the 0.05 level on certain sampling dates.

Table 2.7 - Number of nodules per plant as affected by treatment, for the locations and years studied.

Location	Year	Sampling date	Treatment		
			early	late	no mulch
Canfield[#]	1990	Aug 27	37.9 b[*]	46.6 b	75.9 a
Delhi	1989	Jul 19	11.5	14.7	5.3
		Aug 23	31.7	34.0	19.4
	1990	Jul 18	38.5	33.9	22.6
		Aug 8	65.8	56.8	37.4
Woodstock	1989	Jul 26	42.9	54.8	30.2
		Aug 28	51.1	44.0	27.1
	1990	Jul 25	39.7	29.3	24.2
		Aug 21	71.2	71.9	125.6

[#] read standing and mowed treatments for early and late, respectively.
[*] Not significant differences (P=0.05) among means is shown by the same letters in a row or by absence of letters.

irrigation treatments. In another study, tillage had no statistically significant effect on soybean nodulation and total acetylene reduction activity (Lindemann et al., 1982). But, just as in this study, the no-tillage treatment tended to increase taproot nodulation and acetylene reduction early in the season, with this trend not apparent during the later sampling dates. They concluded that the differences in the root environment of soybeans under different tillage systems are apparently subtle enough not to affect the nodule initiation, nodule development and N_2 fixation of soybeans in the northern Corn Belt.

Table 2.9 shows the dry matter of roots sampled on two occasions during the growing seasons studied. Significant differences at the 0.05 level were observed on the first sampling

Table 2.8 - Nodule dry matter (mg) per plant as affected by treatment, for the locations and years studied.

Location	Year	Sampling date	Treatment		
			early	late	no mulch
Canfield#	1990	Aug 27	121.8 b*	120.7 b	256.7 a
Delhi	1989	Jul 19	59.1 a	67.1 a	23.4 b
		Aug 23	328.9 a	325.4 a	164.1 b
	1990	Jul 18	181.2	221.9	198.0
		Aug 8	516.3	568.7	397.5
Woodstock	1989	Jul 26	166.6	201.3	108.4
		Aug 28	265.5	287.4	164.3
	1990	Jul 25	186.3	204.9	117.4
		Aug 21	293.5	389.5	459.0

read standing and mowed treatments for early and late, respectively.

* Not significant differences (P=0.05) among means is shown by the same letters in a row or by absence of letters.

date at Delhi in 1990 with the late killing treatment presenting less root growth than the no mulch treatment. This agrees with the depressed canopy growth observed due to the delay in emergence for the late killing treatment. For the second sampling date at Delhi in 1990, the late killing treatment showed a larger root dry matter value, when compared to the other treatments, although not statistically significant.

2.2.2.3. Soybean yield components and yield

The observations made on 10 soybean plants sampled at harvest time are listed on Table 2.10a, 2.10b and 2.10c. The number of branches (Table 2.10a) and the dry matter per seed (Table 2.10c) were not statistically different among treatments for any of the location-years studied.

The number of nodes per plant was significantly larger

Table 2.9 - Root dry matter (kg/ha) as affected by treatment, for the locations and years studied.

Location	Year	Sampling date	Treatment		
			early	late	no mulch
Canfield#	1990	Aug 27	253.3*	211.5	361.6
Delhi	1989	Jul 19	148.1	195.5	254.1
		Aug 23	466.9	440.9	417.3
	1990	Jul 18	322.6 ab	255.5 b	376.8 a
		Aug 8	606.5	664.3	532.7
Woodstock	1989	Jul 26	291.9	279.1	266.1
		Aug 28	395.8	460.6	346.1
	1990	Jul 25	367.0	211.6	280.5
		Aug 21	528.7	477.6	540.0

read standing and mowed treatments for early and late, respectively.
* Not significant differences (P=0.05) among means is shown by the same letters in a row or by absence of letters.

for the no mulch treatment at Woodstock in 1990 (Table 2.10a). Other location-years did not present differences among treatments for this variable.

The number of pods per plant was significantly lower for the early killing treatment at Woodstock in 1990. For other location-years no significant differences were observed, but a larger number of pods per plant was counted for the late killing treatment at Delhi in 1990, when compared to the early killing and no mulch treatments.

The counts of number of seeds per pod (Table 2.10b) showed no significant difference among treatments, except for Delhi in 1990 when the mulch treatments had larger number of seeds per pod than the no mulch treatment. This was also the trend in 1989 at Delhi and Woodstock, with a significant difference at the 0.10

Table 2.10a - Yield components as affected by treatment, for the locations and years studied.

Number of nodes per plant

Location	Year	Treatment		
		early	late	no mulch
Canfield#	1990	11.1*	12.0	11.9
Delhi	1989	11.6	11.7	11.6
	1990	15.0	15.1	14.5
Woodstock	1989	10.7	10.2	11.4
	1990	11.3 b	12.2 ab	13.4 a

Number of branches per plant

Location	Year	Treatment		
		early	late	no mulch
Canfield#	1990	2.2	2.1	1.9
Delhi	1989	1.3	1.7	1.9
	1990	2.9	2.7	2.7
Woodstock	1989	2.5	2.6	3.1
	1990	2.4	2.8	2.2

read standing and mowed treatments for early and late, respectively.

* Not significant differences (P=0.05) among means is shown by the same letters in a row or by absence of letters.

Table 2.10b - Yield components as affected by treatment, for the locations and years studied.

Number of pods per plant				
Location	Year	Treatment		
		early	late	no mulch
Canfield[#]	1990	19.6[*]	20.5	24.6
Delhi	1989	17.7	19.9	23.2
	1990	38.8	46.1	34.6
Woodstock	1989	26.7	29.4	36.0
	1990	29.3 b	36.7 a	35.7 a

Number of seeds per pod				
Location	Year	Treatment		
		early	late	no mulch
Canfield[#]	1990	2.35	2.34	2.40
Delhi	1989	2.12	2.25	2.02
	1990	2.28 a	2.30 a	2.21 b
Woodstock	1989	2.27	2.30	2.22
	1990	2.12	2.10	2.11

[#] read standing and mowed treatments for early and late, respectively.
[*] Not significant differences (P=0.05) among means is shown by the same letters in a row or by absence of letters.

Table 2.10c - Yield components as affected by treatment, for the locations and years studied.

Number of seeds per m^2				
Location	Year	Treatment		
		early	late	no mulch
Canfield#	1990	853.7 b*	766.2 b	1293.6 a
Delhi	1989	1298.6	1481.3	1554.6
	1990	2735.3	2197.0	2527.0
Woodstock	1989	2113.2	2187.5	2373.9
	1990	2786.8	3210.0	2979.0

Dry matter (mg) per seed				
Location	Year	Treatment		
		early	late	no mulch
Canfield#	1990	165.1	168.2	170.4
Delhi	1989	158.5	156.1	158.5
	1990	167.0	169.9	177.1
Woodstock	1989	149.3	150.2	154.9
	1990	158.3	159.6	160.0

read standing and mowed treatments for early and late, respectively.

* Not significant differences (P=0.05) among means is shown by the same letters in a row or by absence of letters.

level occurring at Delhi.

The number of seeds per area (Table 2.10c) observed for the mulch treatments at Canfield in 1990 was significantly less than for the no mulch treatment. No statistically significant differences were detected at Delhi and Woodstock at the 0.05 level.

Additional variables measured at harvest time are shown in Table 2.11a and 2.11b. Soybean yields were not significantly different among treatments at Delhi and Woodstock during the study years. The late killing treatment which had lower plant population at Delhi in 1990, still produced soybean yields similar to the early killing and no mulch treatments, by producing more pods per plant and more seeds per pod (Table 2.10b). In 1988, yields were 2568 kg/ha and 2696 kg/ha, respectively, for the mulch and no mulch treatment at Delhi (not significantly different). At Canfield, the no mulch treatment yielded more than the mulch treatments, which presented a lower stand and growth mainly due to the same planting problem that occurred at Delhi in 1990 (same planter was used) and the occurrence of slugs in these mulch plots.

Webber et al. (1987) obtained higher yields for the no-tillage treatment due to a larger weight per seed and larger number of seeds per pod when compared to the conventional tillage treatment. The differences were explained by plant water stress that occurred during flowering and pod fill. In a irrigation study Kadhem et al. (1985b) found that drought stress affected the number of seeds per plant and the hundred seed weight. A significantly larger number of seeds per pod was observed for the mulch treatments as compared to the no mulch treatment at Delhi in 1990, indicating that the mulch treatments may have had a soil moisture advantage.

Seed moisture measured at harvest time (Table 2.11a) was significantly lower for the late killing treatment at Woodstock in 1989. No difference was observed at other location-years.

The plant height measured at harvest time (Table 2.11b) showed no significant difference among treatments for any of the location-years studied. But, the height of the lowest pod was

Table 2.11a - Variables observed at soybean harvest time as affected by treatment, for the locations and years studied.

Soybean yield at 14% moisture (kg/ha)				
Location	Year	Treatment		
		early	late	no mulch
Canfield#	1990	807.9 b*	889.8 b	2229.9 a
Delhi	1989	2171.5	2420.8	2172.5
	1990	3435.1	3439.5	3566.4
Woodstock	1989	3118.2	3008.0	2925.3
	1990	2549.1	2643.0	2700.1

Seed moisture (%)				
Location	Year	Treatment		
		early	late	no mulch
Delhi	1989	14.6	14.7	14.8
	1990	14.0	13.8	14.1
Woodstock	1989	16.9 a	16.4 b	16.7 a
	1990	18.5	18.5	18.3

read standing and mowed treatments for early and late, respectively.
* Not significant differences (P=0.05) among means is shown by the same letters in a row or by absence of letters.

Table 2.11b - Variables observed at soybean harvest time as affected by treatment, for the locations and years studied.

Height of lowest pod (cm)				
Location	Year	Treatment		
		early	late	no mulch
Canfield#	1990	8.2 a*	7.0 b	7.9 a
Delhi	1989	9.5	9.2	8.0
	1990	11.6 a	8.4 b	10.9 a
Woodstock	1989	12.7	11.5	12.0
	1990	12.7	13.4	14.0

Plant height (cm)				
Location	Year	Treatment		
		early	late	no mulch
Canfield#	1990	36.3	34.4	42.8
Delhi	1989	58.5	62.0	56.5
	1990	74.8	67.6	72.1
Woodstock	1989	67.5	61.2	66.2
	1990	65.2	61.7	69.5

read standing and mowed treatments for early and late, respectively.
* Not significant differences (P=0.05) among means is shown by the same letters in a row or by absence of letters.

significantly affected by treatments in 1990 at Delhi and Canfield. For harvesting purposes a larger height of pod setting is desired, but the observed treatment effect was mainly related to problems not inherent to the treatments. At Delhi the lower pod height for the late killing treatment was related to the delay in growth caused by the emergence problem discussed earlier. At Canfield, a lower height of pod setting for the mowed treatment could be associated with the generally poorer stand observed for this treatment, probably due to a larger slug population surviving under the mowed mulch as opposed to the standing mulch.

2.2.2.4. Summary

In summary, soybean growth was not significantly affected by the presence of a rye mulch on the soil surface with the exception of growth at Canfield and early season growth at Delhi in 1990. The depressed early season growth observed at Delhi is considered to be not representative of the cover crop system here studied, since minor adjustments in the planter used would solve the problem. For example, using a larger sized ripple coulter in combination with wire brushes or trash whippers and adding weights to the planter would enhance residue cutting and assure good seed-soil contact. On the other hand, the depressed soybean growth at Canfield points at a need for more research if the system is to be used on clay soils.

Slight yellowing of soybean leaves was observed at Delhi in 1988 and at Delhi and Woodstock in 1990, but it did not affect soybean growth or yield.

The tendency of larger nodule biomass and number on some sampling dates and the higher number of seeds per pod observed in some years for the mulch treatments are an indication that less water stress may have been occurring under those treatments when compared to the no mulch treatment.

A lower height of pod setting, which is detrimental for combine harvesting, was observed at Canfield and Delhi in 1990, but only because of the problems mentioned above.

Major soybean phenological stages such as flowering, pod

setting and harvest maturity were generally not affected by the presence of a rye mulch.

Significant soybean yield differences among treatments were not detected by the number of replications used during the study years, with the exception of Canfield were the mulch treatments yielded less than the no mulch treatment.

2.2.3. Soil Water Measurements

2.2.3.1. Delhi 1988

Soil water measured at Delhi during 1988 is shown in Figure 2.10 for two depths in the row and interrow positions. By comparing Figure 2.10A and 2.10B it can be noticed that the differences between the mulch and no mulch treatments were more pronounced in the interrow than in the row position. The graphs also show that considerable moisture was saved in the 0-30 cm layer due to the presence of the mulch .

For the 30-60 cm layer, differences between treatments and positions were not as pronounced, with the no mulch treatment having higher soil water content during the beginning of the growing season. This could have been due to water extraction by the growing cover crop prior to soybean planting.

Coefficients fitted to exponential drying curves during selected periods at Delhi are listed in Table 2.12. Significant differences between treatments were detected for both interrow and row positions for the first major drying period at Delhi in 1988 (day 174-187). The mulch treatment had lower drying coefficients indicating that evapotranspiration was proceeding at a slower rate than for the no mulch treatment. Drying coefficients within the no mulch treatment were significantly higher for the interrow position, again indicating a faster evapotranspiration rate for that position, as compared to the row position. The remaining drying periods had coefficients not significantly different at the 0.05 level, except for the days 249-259, when the mulch treatment presented lower drying coefficients. For the days 189-196, treatments were significantly different at the 0.10 level, and overall drying coefficient means were lower for the mulch

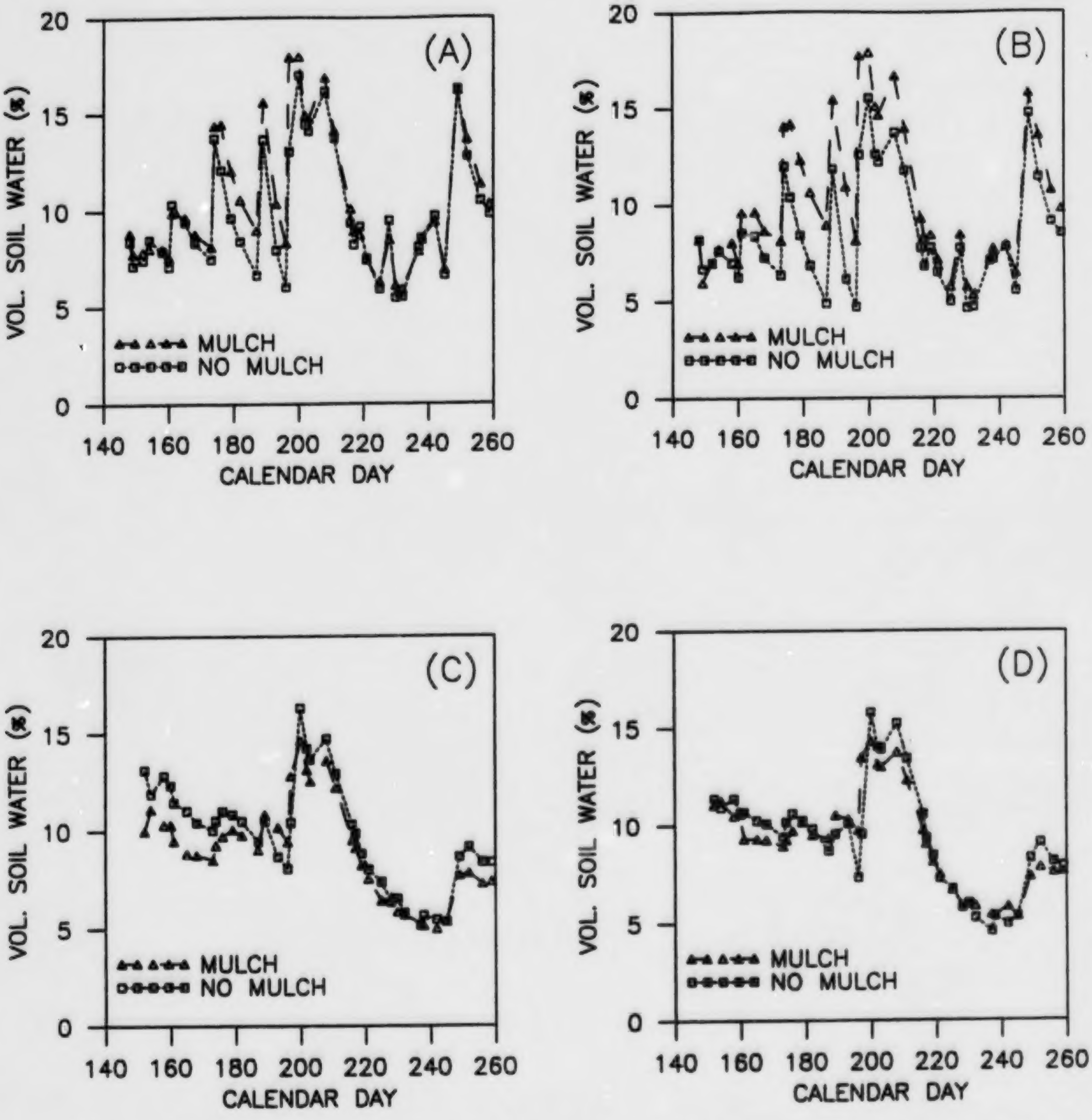

Figure 2.10 - Volumetric soil water (%) measured during 1988 at Delhi for the mulch and no-mulch treatments at the following positions and depths: (A) 0-30 cm row, (B) 0-30 cm interrow, (C) 30-60 cm row and (D) 30-60 cm interrow.

Table 2.12 - Drying coefficients (d^{-1}) for the surface layer (0-10 cm)# layer during selected drying periods at Delhi.

Year	Drying period	Position*	Treatment		
			early	late	no mulch
1988	174-187	R	-	0.0369aA$	0.0593bA
		IR	-	0.0335aA	0.0699bB
	189-196	R	-	0.0955	0.1231
		IR	-	0.0918	0.1408
	208-217	R	-	0.0681	0.0719
		IR	-	0.0754	0.0750
	249-259	R	-	0.0481aA	0.0562bA
		IR	-	0.0503aA	0.0610bA
1989	129-144	R	0.0040aA	0.0215bA	0.0066aA
		IR	0.0112aA	0.0280bA	0.0074aA
	153-163	R	0.0688	0.0715	0.0674
		IR	0.0681	0.0687	0.0710
	174-184	R	0.0564bA	0.0502bA	0.0304aA
		IR	0.0484aA	0.0504aA	0.0393aA
	186-200	R	0.1460	0.0962	0.1338
		IR	0.1024	0.1047	0.1224
1990	159-166	R	0.1205bA	0.0872aA	0.1569cA
		IR	0.1088bA	0.0837aA	[illegible].1428cA
	169-173	R	0.1432	0.1287	0.1687
		IR	0.1332	0.1363	0.1695
	176-187	R	0.1308	0.0687	0.1379
		IR	0.1004	0.0935	0.1052
	190-194	R	0.2437	0.1617	0.1780
		IR	0.1598	0.1581	0.2017
	204-215	R	0.2130	0.1578	0.1843
		IR	0.1473	0.1892	0.2166

0-30 cm for Delhi 1988.
* R=Row, IR=Interrow.
$ Not significant differences (P=0.05) among treatment means within a position is shown by the same lower case letters in a row or by absence of letters. Not significant differences (P=0.05) between position means within a treatment is shown by the same capital letters in a column or by absence of letters.

treatments.

Statistical analysis of soil water values measured at specific dates in 1988 at Delhi for the 0-30 cm layer showed no significant difference between treatment means at planting time (day 147), but significant differences at flowering (day 197) in both positions (Table 2.13). In the 30-60 cm layer significantly

Table 2.13- Volumetric soil water (%) in the surface layer (0-10 cm)# around planting, flowering and pod filling time.

Location	Year	Position*	Treatment		
			early	late	no mulch
Planting					
Delhi	1988	R	-	8.8$	8.4
		IR	-	8.2	8.2
	1989	R	15.2aA	11.0bA	15.0aA
		IR	14.0aA	10.4bA	15.1aA
	1990	R	15.6	16.5	18.0
		IR	16.3	17.4	15.5
Woodstock	1989	R	39.3aA	38.2aA	31.8bA
		IR	40.5aA	38.8aA	28.3bB
	1990	R	41.8	39.9	37.3
		IR	40.0	39.5	36.4
Canfield	1990	R	35.5	32.1	27.5
		IR	35.3	37.4	27.0
Flowering					
Delhi	1988	R	-	17.9aA	13.0bA
		IR	-	17.7aA	12.6bA
	1989	R	7.6	8.8	10.7
		IR	7.9	7.5	10.1
	1990	R	10.9	13.8	13.7
		IR	13.0	13.6	10.9
Woodstock	1989	R	26.4	22.4	22.6
		IR	27.3	25.7	18.7
	1990	R	47.3	45.7	46.2
		IR	43.9	44.4	43.5
Canfield	1990	R	42.8	37.6	35.9
		IR	39.1	39.6	38.6
Pod filling					
Delhi	1989	R	6.6	8.7	6.5
		IR	7.0	8.2	6.8
	1990	R	6.5	7.5	5.8
		IR	6.8	6.9	5.8
Woodstock	1989	R	19.8	16.9	16.9
		IR	20.4	17.6	16.2
	1990	R	36.7	36.5	38.1
		IR	34.5	36.0	37.9
Canfield	1990	R	44.9	44.1	44.1
		IR	44.2	43.9	43.5

0-30 cm for Delhi 1988. * R=Row, IR=Interrow.

$ Not significant differences (P=0.05) among treatment means within a position is shown by the same lower case letters in a row or by absence of letters. Not significant differences (P=0.05) between position means within a treatment is shown by the same capital letters in a column or by absence of letters.

Table 2.14 - Volumetric soil water (%) in the 10-30 cm layer around planting, flowering and pod filling time.

Location	Year	Position*	Treatment		
			early	late	no mulch
Planting					
Delhi	1989	R	14.2$	11.1	14.9
		IR	14.5	12.8	15.5
	1990	R	18.5bA	23.0aA	17.9bA
		IR	18.6aA	15.3bB	18.2aA
Woodstock	1989	R	35.3aA	34.4aA	27.5bA
		IR	36.7aA	33.9aA	29.0bA
	1990	R	34.4	35.7	36.2
		IR	33.7	36.1	35.0
Canfield	1990	R	29.7bA	35.3abA	40.0aA
		IR	31.1aA	38.0aA	37.0aA
Flowering					
Delhi	1989	R	7.7	9.0	8.2
		IR	6.9	9.0	8.2
	1990	R	16.4	16.6	13.3
		IR	17.7	15.7	12.8
Woodstock	1989	R	19.7	21.1	19.5
		IR	26.4	23.7	25.0
	1990	R	34.8	38.3	37.5
		IR	34.6	35.1	36.2
Canfield	1990	R	38.3	39.9	35.9
		IR	39.8	39.4	36.3
Pod filling					
Delhi	1989	R	5.7	6.3	5.6
		IR	5.7	6.4	5.5
	1990	R	9.6	8.8	7.0
		IR	8.3	8.3	8.6
Woodstock	1989	R	12.6	13.1	13.9
		IR	16.9	13.3	12.9
	1990	R	30.6	32.7	33.0
		IR	30.1	30.7	33.0
Canfield	1990	R	46.5	44.8	44.3
		IR	46.4	45.8	43.0

* R=Row, IR=Interrow.

$ Not significant differences (P=0.05) among treatment means within a position is shown by the same lower case letters in a row or by absence of letters. Not significant differences (P=0.05) between position means within a treatment is shown by the same capital letters in a column or by absence of letters.

Table 2.15 - Volumetric soil water (%) in the 30-60 cm layer around planting, flowering and pod filling time.

Location	Year	Position*	Treatment early	Treatment late	Treatment no mulch
Planting					
Delhi	1988	R	-	10.0bA[$]	13.1aA
		IR	-	11.0aA	11.4aA
	1989	R	9.2bA	7.7bA	11.6aA
		IR	9.9bA	8.4bA	11.8aA
	1990	R	15.1	11.8	10.8
		IR	15.1	14.8	14.6
Woodstock	1989	R	29.9aA	22.2bA	13.4cA
		IR	32.5aA	20.3bA	16.2bA
	1990	R	30.2	33.4	34.6
		IR	32.9	32.2	36.6
Flowering					
Delhi	1988	R	-	12.8	10.4
		IR	-	13.5	9.6
	1989	R	7.6	7.9	8.4
		IR	7.3	8.6	7.9
	1990	R	13.9	13.4	12.2
		IR	13.8	14.3	10.7
Woodstock	1989	R	24.0aA	20.5abA	14.4bA
		IR	27.1aA	16.8bA	17.4bA
	1990	R	37.0	37.3	43.1
		IR	37.8	33.9	46.5
Pod filling					
Location	Year	Position*	Treatment[$] early	Treatment[$] late	Treatment[$] no mulch
Delhi	1989	R	4.8	5.9	6.5
		IR	4.9	5.2	4.4
	1990	R	6.8	6.6	6.8
		IR	6.6	7.1	5.1
Woodstock	1989	R	19.7	19.0	15.5
		IR	21.2	18.4	14.4
	1990	R	32.4	30.7	37.8
		IR	29.1	28.5	35.6

* R=Row, IR=Interrow.

$ Not significant differences (P=0.05) among treatment means within a position is shown by the same lower case letters in a row or by absence of letters. Not significant differences (P=0.05) between position means within a treatment is shown by the same capital letters in a column or by absence of letters.

higher soil water means were measured for the no mulch treatment at planting time, and significantly larger means at the 0.10 level for the mulch treatment at flowering (Table 2.14).

2.2.3.2. Delhi 1989

Figure 2.11 shows percentage soil water in three layers (0-10, 10-30 and 30-60 cm) measured during 1989 at Delhi. In 1989, the decrease in soil water in the late killing treatment just prior to soybean planting (day 144) at all depths indicates the effect of water extraction by the growing rye (Figure 2.11A, 2.11B and 2.11C). But rainfalls following soybean planting recharged the profile under all three treatments, so that the differences between treatments disappeared.

Soil moisture was also significantly higher for early killed rye in the early part of the season in one year of a 2-year study done by Munawar et al. (1990), because there was less soil moisture depletion due to the growing rye.

The three graphs on Figure 2.11 show that individual rainfalls occurring after the end of June 1989 (day 182) where not large enough to replenish the 30-60 cm layer. The 0-10 cm layer presented slightly higher soil water percentage under the no mulch treatment, while the 10-30 cm layer presented somewhat higher water contents under the late kill treatment. At 30-60 cm depth, no difference among treatments occurred.

The drying coefficients fitted to selected periods in 1989 at Delhi are listed on Table 2.12. Period 129-144 shows the significant effect of water extraction by the growing rye under the late killing treatment on the drying rate of the surface layer. Period 174-184 also showed significant differences among the treatments with faster drying observed in the row position for the mulch treatments. The soybean growth was enough to shade the row position by the end of June (day 182) and the soybean planting procedure had left the row position free of mulch. This indicates that a faster drying coefficient in the row position could be associated with higher water extraction by the soybeans for the mulch treatments, since soil evaporation should be similar for all

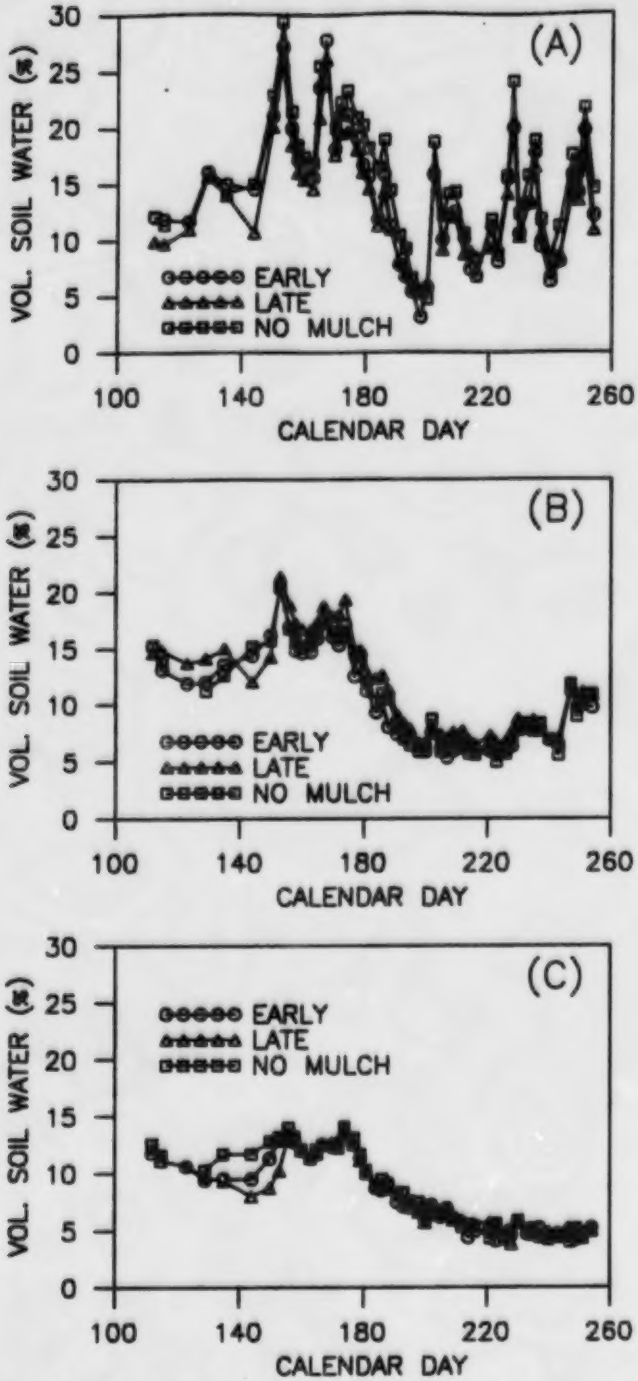

Figure 2.11 - Volumetric soil water (%) measured at Delhi in 1989 for the early, late and no-mulch treatments at the following depths: (A) 0-10 cm, (B) 10-30 cm and (C) 30-60 cm.

treatments in the row position. Periods 153-163 and 186-200 showed no significant differences among coefficient means for all treatments.

Aase and Tanaka (1987) also verified that soil drying was influenced by tillage and residue quantity. Most rapid initial drying occurred on bare fallow plots and most slowly drying on flat straw plots. But, after about 10 days, treatment differences no longer existed and total water lost did not differ between treatments. Zhai et al. (1990) had similar results with early season drying coefficients significantly higher for the conventional treatment compared to the no-tillage treatment. At later crop stages the effect of tillage on drying rates was no longer significant.

Table 2.13 shows the comparison of treatment soil water means at 0-10 cm on specific dates. Soil water was significantly lower at Delhi for the late killing treatment at planting time in 1989, but no significant differences were observed during soybean flowering and pod filling. No significant differences were observed for the 10-30 cm layer (Table 2.14) on all tested dates, although larger soil water was measured for the late killing treatment. The 30-60 cm layer (Table 2.15) showed significantly lower soil water contents for the mulch treatments at planting time in 1989. At flowering and pod filling there was no significant difference among treatments.

2.2.3.3. Delhi 1990

The 1990 measurements (Figure 2.12A, 2.12B and 2.12C) did not show the drying effect of the growing rye as well as in 1989, since rainfalls occurred after killing time and before soybean planting. In general, 1990 was a season with more frequent rainfalls than 1989 (Figure A.2 and A.3), especially around flowering (day 190) and pod filling time (day 215). For the 0-10 cm layer the late killing treatment presented larger soil water values (Figure 2.12A) during the period preceding flowering (day 190). The 10-30 cm layer showed more moisture for the early killing treatment during the same period. The no mulch treatment had lower soil water

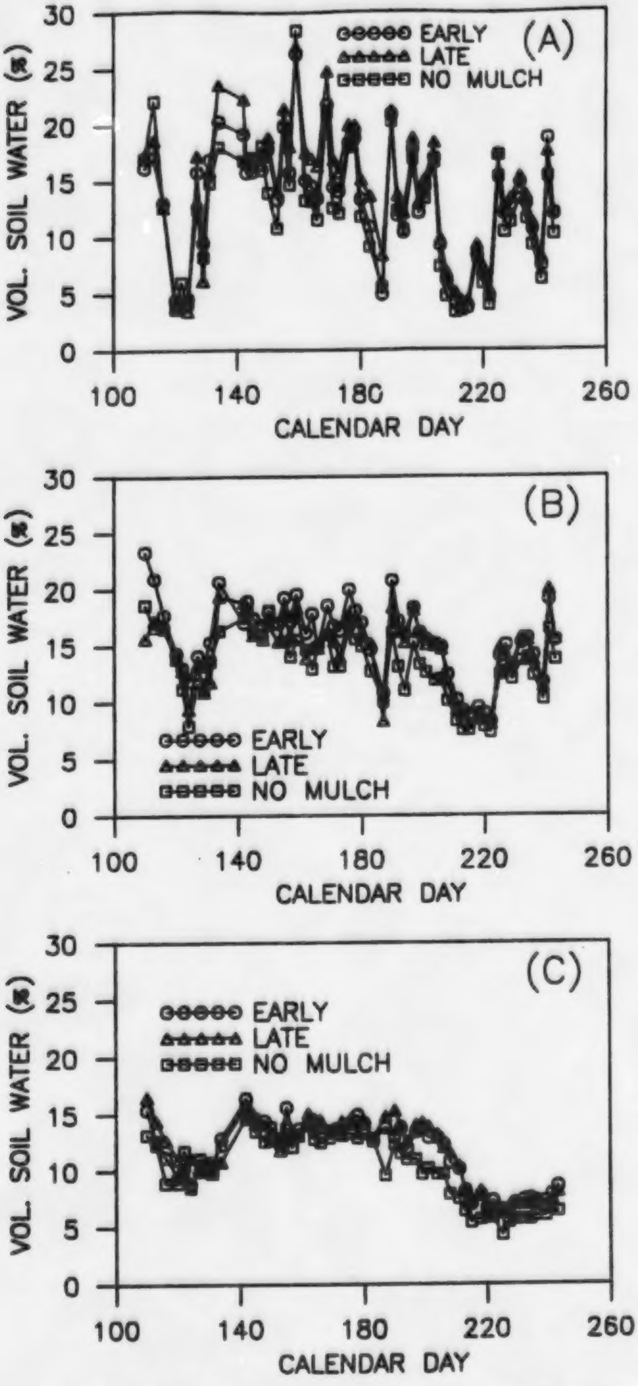

Figure 2.12 - Volumetric soil water (%) measured at Delhi in 1990 for the early, late and no-mulch treatments at the following depths: (A) 0-10 cm, (B) 10-30 cm and (C) 30-60 cm.

values during the flowering and pod filling period at depths 10-30 cm and 30-60 cm.

The first drying period (159-166) after soybean planting (Table 2.12) revealed significant differences among treatments, with the late killing treatment showing the slowest drying rate and the no mulch treatment the highest drying rate. The early killing treatment had drying coefficients significantly higher than the late killing treatment, and significantly lower than the no mulch treatment. No significant effect of measurement position was detected. The subsequent periods showed the same tendency but no significant differences were observed.

The comparison of treatment soil water means at 0-10 cm on specific dates showed no significant differences at soybean planting, flowering and pod filling.

The 10-30 cm layer (Table 2.14) presented higher moisture in the row position for the late killing treatment and lower moisture in the interrow position at planting time, probably an effect of previous rye row positioning. No significant differences were observed at flowering and pod filling time, although larger soil water was measured for the mulch treatments. The 30-60 cm layer (Table 2.15) showed no significant differences at planting time, flowering and pod filling.

2.2.3.4. Woodstock 1989

Figure 2.13 shows the soil water content measured at Woodstock during 1989 for the three soil layers studied. For the surface layer (0-10 cm), results obtained in both measurement positions (row and interrow) are shown. No effect of soil drying due to water extraction by the rye was observed in 1989, when rye growth was reduced and the soybean residue from the previous summer was covering the soil surface. As a result, the no mulch treatment had less soil water than the mulch treatments at the beginning of measurements.

Soil cultivation just prior to soybean planting in 1989 (day 149) resulted in further drying of the no mulch plots, which then presented lower soil water for most of the growing season

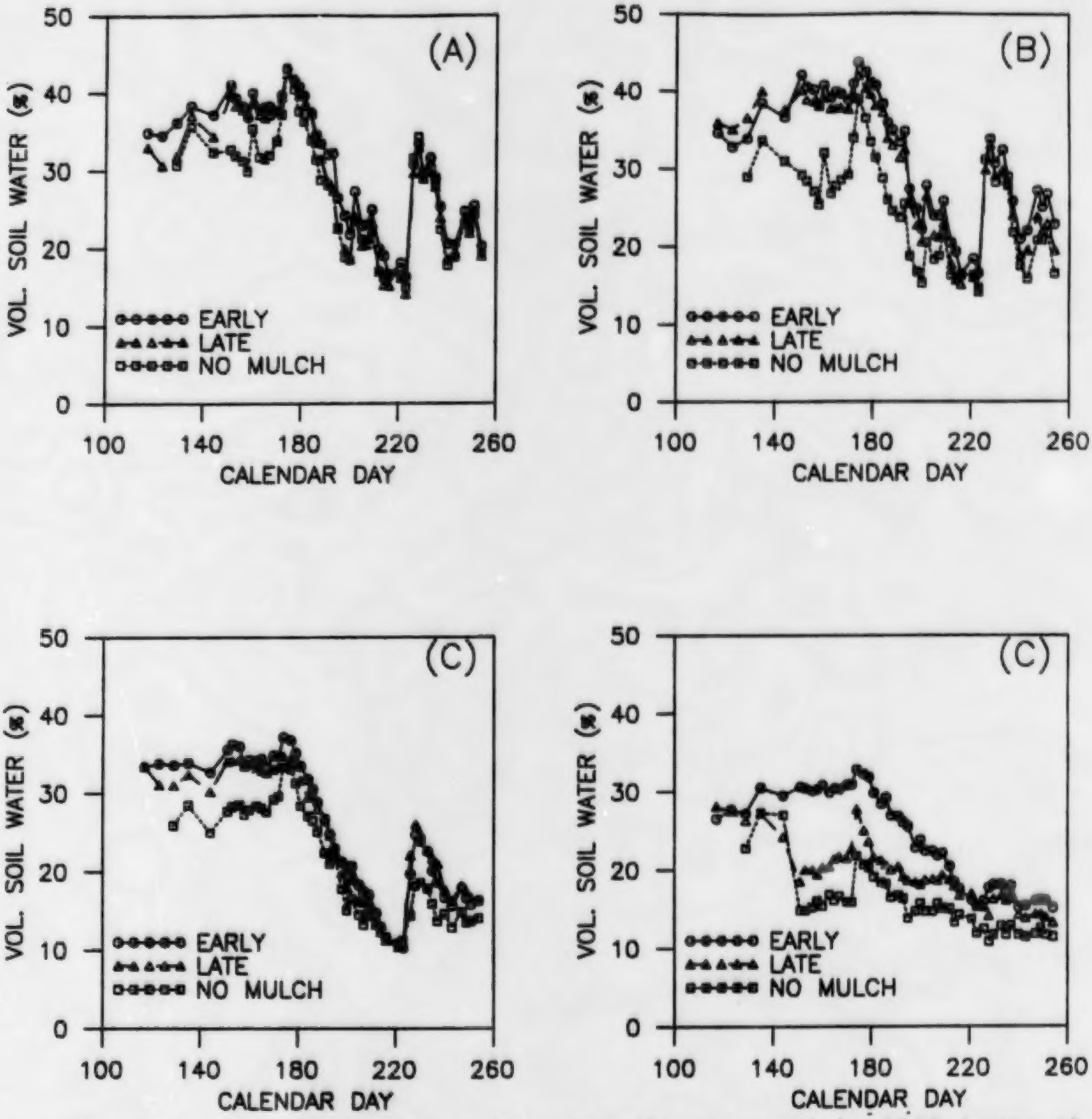

Figure 2.13 - Volumetric soil water (%) measured in 1989 layer at Woodstock for the early, late and no-mulch treatments during the following depths: (A) 0-10 cm row position ,(B) 0-10 cm interrow position, (C) 10-30 cm and (D) 30-60 cm.

(Figure 2.13A and 2.13B). This drying was more pronounced in the interrow position of the no mulch treatment (Figure 2.13B). Table 2.16 lists drying coefficients obtained for the surface layer at Woodstock during selected periods. No statistically significant difference among treatments was detected, but drying coefficients were largest for the interrow position in the no mulch treatment.

Comparison of soil water means in the surface layer at specific times during the 1989 growing season at Woodstock are listed on Table 2.13. Differences among treatments were significant for volumetric soil water measured on planting date, with the no mulch treatment having the lowest mean, due to the drying effect of cultivation. Volumetric soil water measured at flowering and pod filling were not statistically different for the 0-10 cm layer.

Treatment means for the 10-30 cm and 30-60 cm layer obtained at planting time also showed less soil water in the soil profile under the no mulch treatment (Table 2.14 and 2.15), again due to the drying effect of the cultivation performed prior to soybean planting. The 30-60 cm layer also showed less moisture for the no mulch treatment at flowering time, while the 10-30 cm layer showed no significant difference among treatments for that date. At pod filling no significant difference was detected in the 10-30 cm and 30-60 cm layer.

2.2.3.5. Woodstock 1990

Some drying of the surface layer caused by the growing rye was observed in 1990 (Figure 2.14A and 2.14B) before day 140. Again, cultivating resulted in a sharp soil moisture decrease (around day 150) in the no mulch treatment. The subsequent measurements (day 150-180) show a higher soil water content for the mulch treatments, particularly in the interrow position. By comparing 1989 and 1990 it can be seen that during most of 1990 the soil moisture conditions were more favourable for growth since the surface layer had moisture levels at or around field capacity (33.2%).

Table 2.16 lists drying coefficients obtained for the surface layer at Woodstock during selected periods in 1990. The

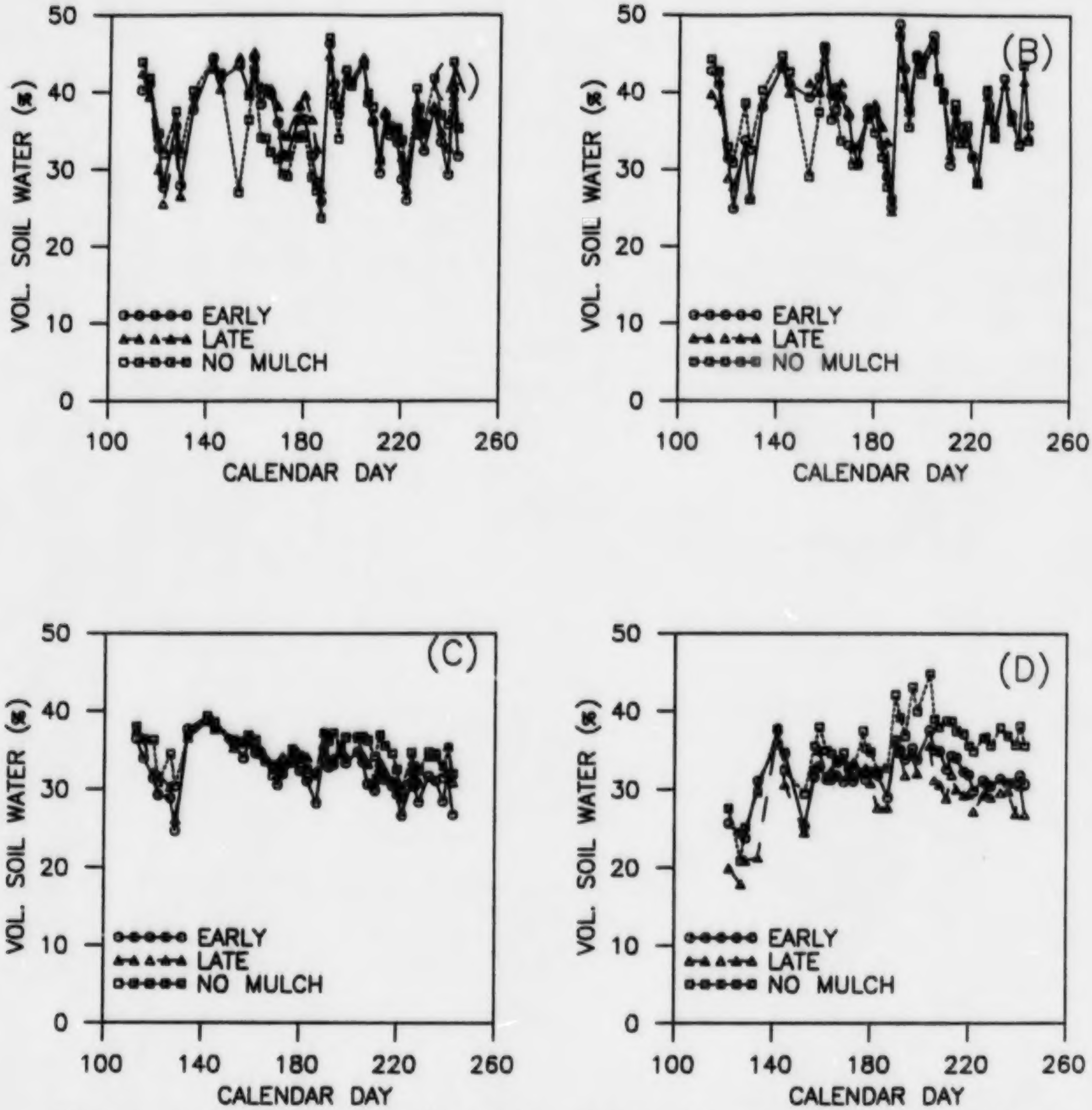

Figure 2.14 - Volumetric soil water (%) measured in 1990 at Woodstock for the early, late and no-mulch treatments at the following depths: (A) 0-10 cm row position, (B) 0-10 cm interrow position, (C) 10-30 cm and (D) 30-60 cm.

Table 2.16 - Drying coefficients (d^{-1}) for the surface layer (0-10 cm) during selected drying periods at Woodstock.

Year	Drying period	Position*	Treatment		
			early	late	no mulch
1989	174-191	R	0.0171$	0.0205	0.0272
		IR	0.0153	0.0166	0.0321
	209-216	R	0.0603	0.0728	0.0523
		IR	0.0646	0.0687	0.0545
	233-240	R	0.0589	0.0694	0.0711
		IR	0.0604	0.0611	0.0648
1990	159-173	R	0.0270abA	0.0220aA	0.0333bA
		IR	0.0243aA	0.0204aA	0.0334bA
	180-187	R	0.0589	0.0521	0.0445
		IR	0.0521	0.0484	0.0550
	190-194	R	0.0535	0.0645	0.0752
		IR	0.0578	0.0443	0.0902

* R=Row, IR=Interrow.
$ Not significant differences (P=0.05) among treatment means within a position is shown by the same lower case letters in a row or by absence of letters. Not significant differences (P=0.05) between position means within a treatment is shown by the same capital letters in a column or by absence of letters.

first drying period (159-173) in 1990 showed significant difference among treatments with the no mulch treatment having higher drying rates in both positions (row and interrow), when compared to the mulch treatments. Other drying periods showed no significant difference among treatment means.

Soil water means in the 0-10 cm, 10-30 cm and 30-60 cm layers at specific times during the 1990 growing season at Woodstock were not significantly different (Table 2.13, 2.14 and 2.15).

2.2.3.6. Canfield 1990

Figure 2.15 shows the volumetric soil water percentage measured at Canfield during 1990 for the layers 0-10, 10-30 and 30-60 cm. For a limited time period the 0-10 cm layer showed less moisture under the no mulch treatment than under the mulch treatment (Figure 2.15A). The standing mulch treatment had significantly less soil moisture in the row position of the 10-30

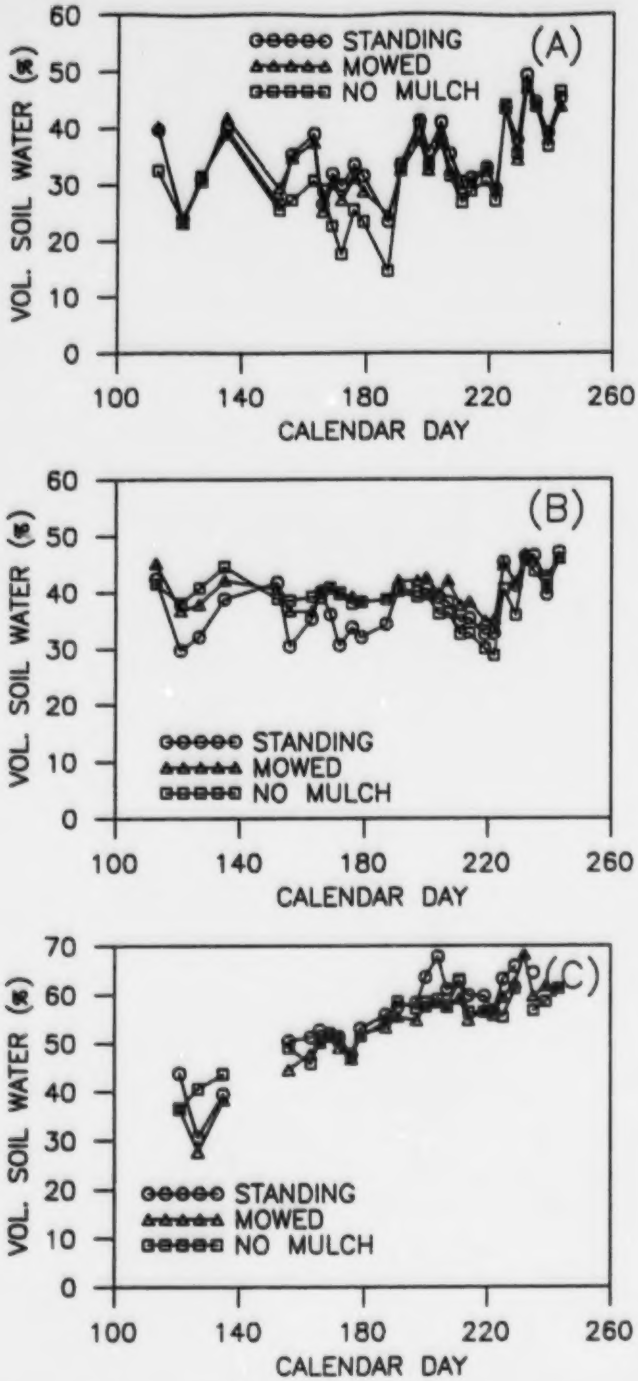

Figure 2.15 - Volumetric soil water (%) measured at Canfield in 1990 for the standing, mowed and no-mulch treatments at the following depths: (A) 0-10 cm, (B) 10-30 cm and (C) 30-60 cm.

cm layer early in the season (Table 2.14). No significant differences were detected at flowering and pod filling time. The extremely high water contents measured in the 30-60 cm layer at Canfield are not realistic and point to a practical difficulty in interpreting the TDR signal from long rods on that soil type.

2.2.3.7. Summary

In summary, a drying effect of the growing rye was observed at the sandy soil site (Delhi) during the driest spring studied (1989). This drying was more pronounced for the late killing date treatment, but by soybean planting time rainfalls had replenished the soil profile under all treatments.

Soil surface drying rates were decreased by the presence of a mulch early in the soybean growing season, especially for the late killing date treatment. Cultivating of the no-mulch plots at the loam soil site (Woodstock) produced a sharp decrease in soil moisture early in the growing season. Significant differences in soil moisture among treatments later in the season were only observed at Delhi during the particularly dry 1988 season.

2.2.4. Soil Temperature Measurements

2.2.4.1. Delhi

The frequency distribution of hourly soil temperatures at Delhi during the soybean growing season in 1989 and 1990 is shown in Figure 2.16. During all months studied there was a tendency for the mulch treatments to have less frequent hours in the cooler and in the warmer soil temperature classes.

The magnitude of this difference was small, averaging 4.5% less hours in the coldest and warmest temperature classes for the late killing than for the no mulch treatment; and 3% less hours for the early killing than for the no mulch treatment.

The maximum difference in the frequency of soil temperature between late killing and no mulch treatment was 18% for the cooler temperature class of 15-20 C in July of 1990 and 14% for the warmer temperature class of 25-30 C in May of 1990. That is, the no mulch treatment had, respectively, 18 and 14% more hours in these classes than the late killing treatment.

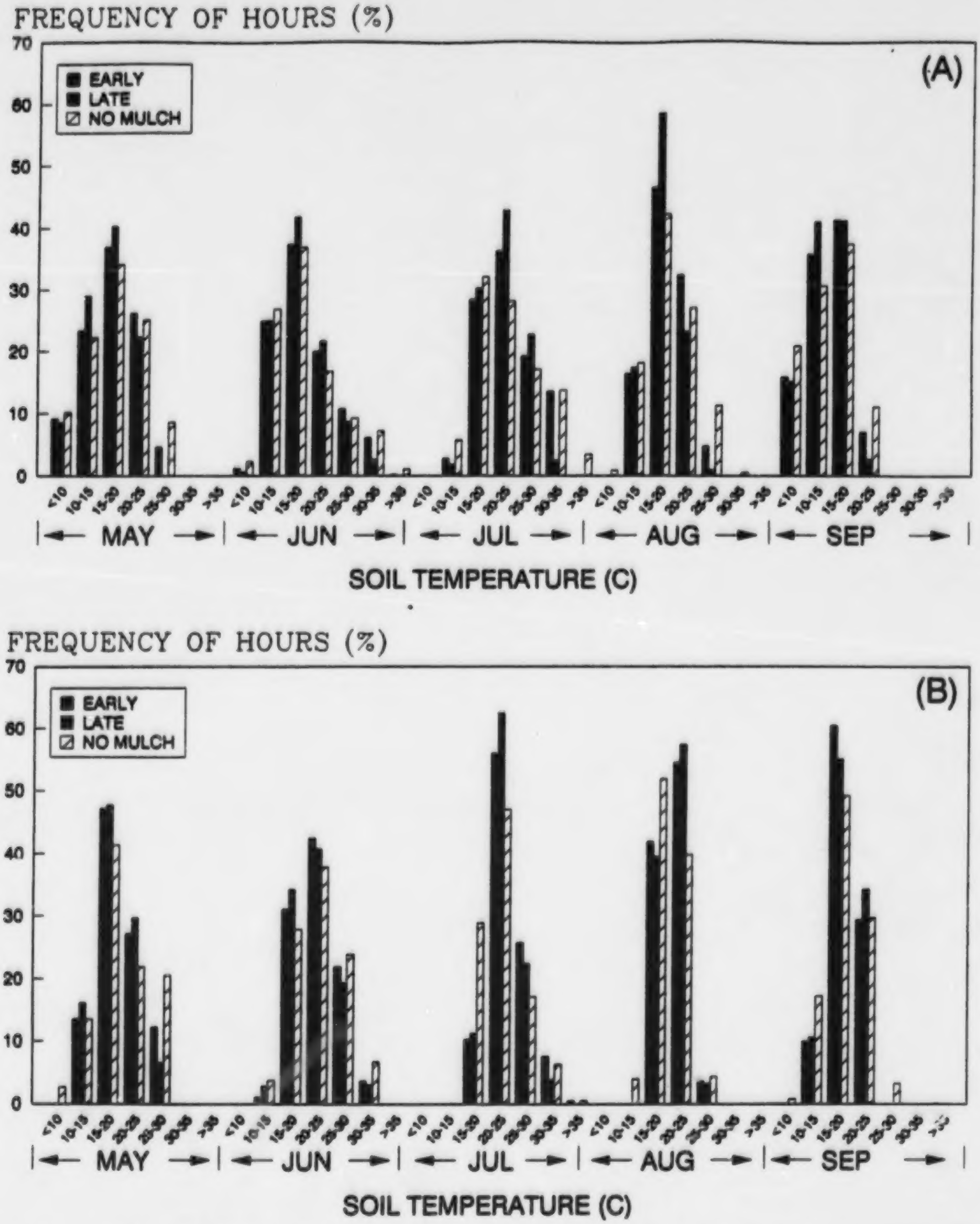

Figure 2.16 - Relative frequency of hours in each soil temperature class measured at 5 cm depth, for months after planting at Delhi in (A) 1989 and (B) 1990 for the early, late and no-mulch treatments. Data shown for May refer to the last week in the month.

On the other hand, the mulch treatments had a larger frequency of hours than the no mulch treatment in the middle range temperatures. An average of 8% more hours occurred in the middle range temperatures for the late killing than for the no mulch treatment; and 5% more hours for the early killing than the no mulch treatment. The late killing treatment had a maximum of 17% more hours than the no mulch treatment in the 20-25 C class in August of 1990.

The effect of both mulch treatments on the frequency distribution of hourly soil temperatures was similar, but the magnitude of the differences between early killing and no mulch versus late killing and no mulch treatments were smaller.

2.2.4.2. Woodstock and Canfield

Frequency distributions of hourly soil temperatures for Woodstock during the soybean growing season of 1989 and 1990 and Canfield in 1990 are shown in Figures 2.17 and 2.18, respectively. The trends observed were identical to the ones described for Delhi and the magnitude of the differences was similar. The frequency of extremes was reduced, and the frequency of mid-range temperatures was enhanced.

The main reason for the shift in frequency distribution was that the mulch had an effect on the amplitude of daily soil temperatures. During daytime the maximum soil temperature was decreased and during nighttime the minimum soil temperature was increased.

But, although the extreme soil temperatures were greatly affected by the presence of a mulch in the treatments studied during some days (Figure 2.19), the integrated effect over the whole growing season was not large. The no-mulch treatment was characterized by less than 10% higher frequency of extreme temperatures, while the mulch treatment had less than 10% higher frequency of medium temperatures.

Large soil temperature differences between mulch and no-mulch treatments have been observed elsewhere, mainly by comparing their maximum and minimum soil temperatures. NeSmith et al. (1987)

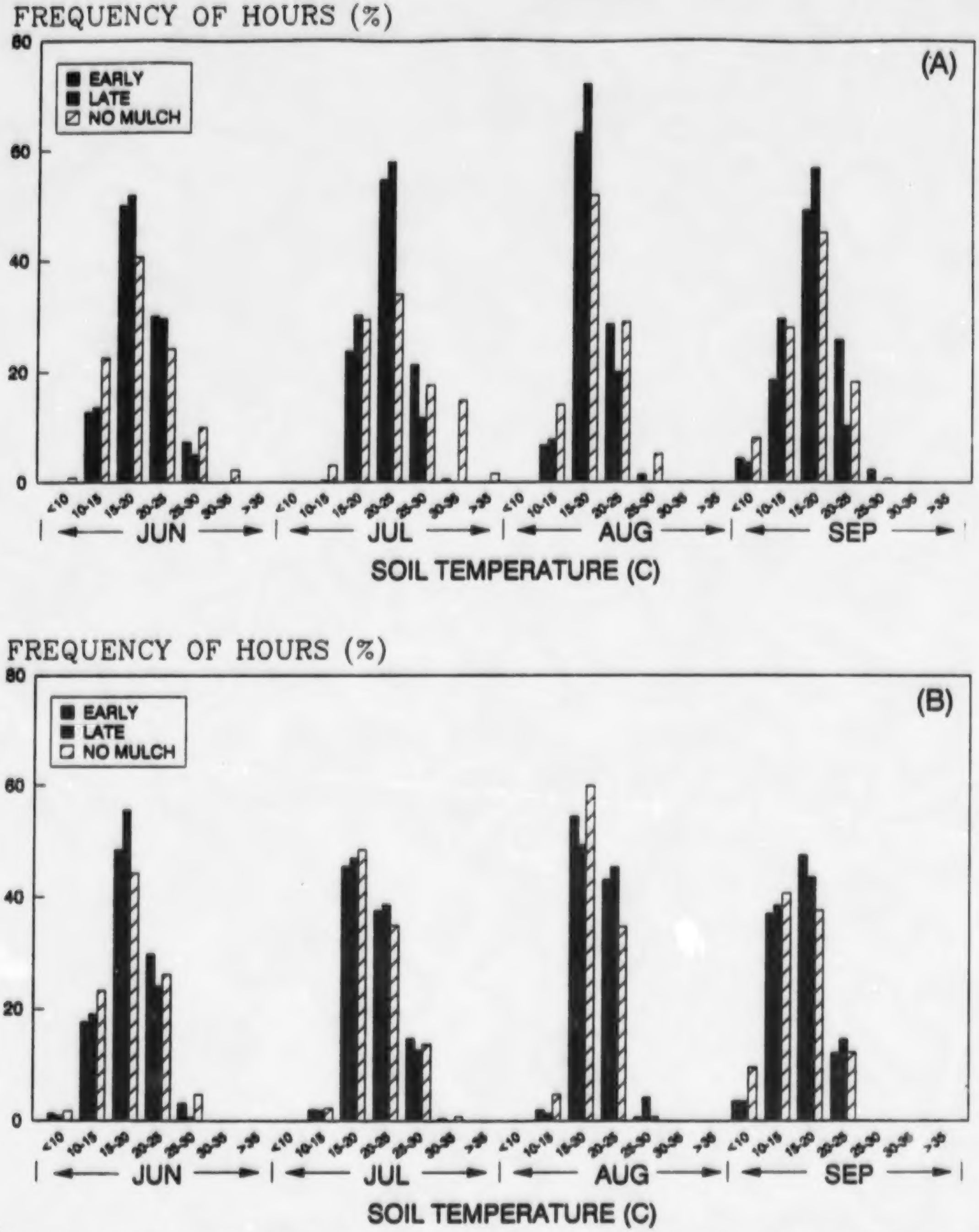

Figure 2.17 - Relative frequency of hours in each soil temperature class measured at 5 cm depth, for months after planting at Woodstock in (A) 1989 and (B) 1990 for the early, late and no-mulch treatments.

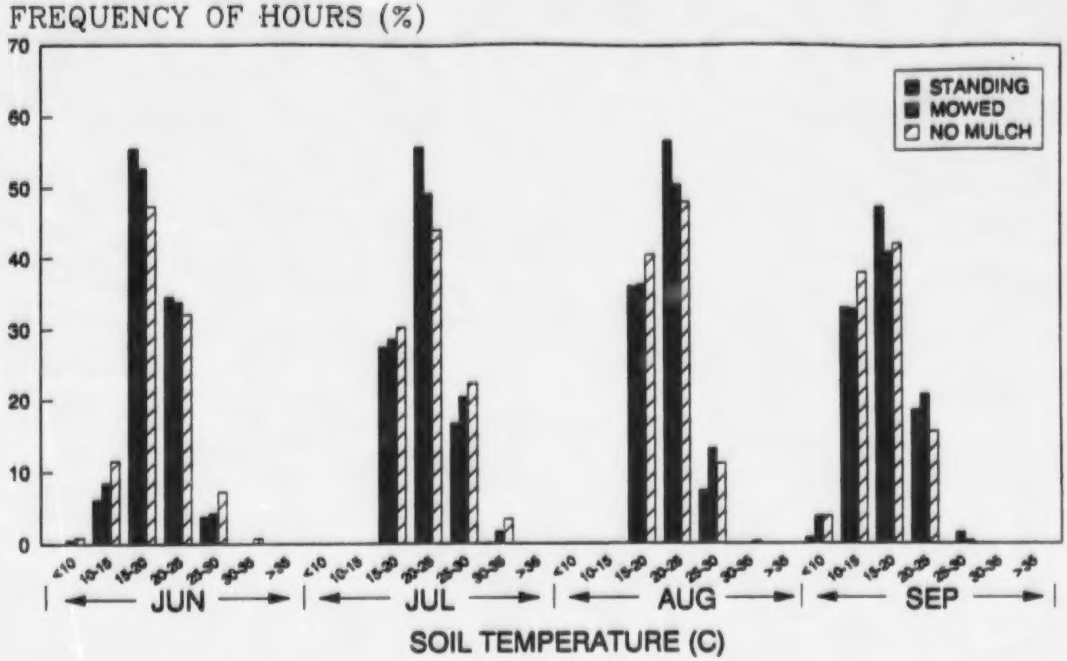

Figure 2.18 - Relative frequency of hours in each soil temperature class measured at 5 cm depth, for months after planting at Canfield in 1990 for the standing, mowed and no-mulch treatments.

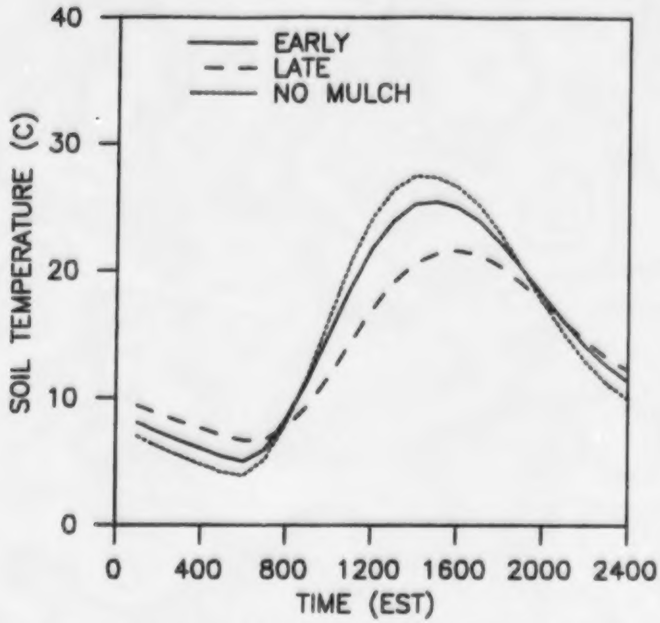

Figure 2.19 - Hourly soil temperature measured at 5 cm depth at Delhi on May 28, 1989, for the three treatments studied.

measured soil temperatures at 2.5 cm at 1500 h and found that differences between no-tillage and plowing were sometimes as much as 5 to 8 C. Gupta et al. (1983) found differences as large as 12 C in maximum soil temperatures, and as large as 6 C in minimum soil temperature due to the presence of a residue cover.

Lindemann and Ham (1979) showed that maximum soybean dry weight and nodule number occurred at 25 C and not at 30 C. Tollner et al. (1984) concluded that the reduced maximum temperatures under a no-till mulch benefit soybean growth and development.

The data presented here show that over the whole growing season, soil temperature differences between mulch and no mulch treatments were not very pronounced. However, lower variability in temperatures under the mulch treatments could benefit microbial populations and activity, as well as crop growth.

2.3. Conclusions

The rye mulch/soybean system studied proved satisfactory for soybean production on a sandy and a loam soil. On a clay soil, difficulties associated with excess fall moisture and winter kill interfered with cover crop establishment, while planter problems and slug damage in the spring decreased soybean yield on mulched plots. More research would be necessary if the system is to be adapted to clay soils, but our experience was not encouraging.

On the sandy and the loam soil site, rye mulch amount was significantly larger for the late killing date as opposed to an early killing date. Differences between soil drying rates under early killed rye mulch and late killed rye mulch were observed in 1990 at Delhi, but generally soil water content between the two mulch treatments was not different. Soil water conservation under mulch, although significant for short periods early in the season during one year, did not affect early soybean growth due to timely rainfalls.

For rye mulch amounts larger than 2000 kg/ha, no significant increases in percentage ground cover were gained by delaying rye cover crop killing. Also, mulch decomposition proceeded at a faster

rate for large mulch amounts.

Although the rye mulch had a significant effect on the soil surface drying rate early in the soybean growing season, shading of the soil surface by the soybean canopy plus a substantial decrease in the amount of mulch present on the soil surface, resulted in little difference between mulch and no mulch conditions later in the season.

Analysis of hourly soil temperatures measured under mulch and no mulch treatments revealed that extreme temperatures are more frequent under the bare soil condition. Over the whole growing season these differences were limited to a small percentage of hours, but the lower variability of temperature under the mulch may have benefited microbial activity and root growth slightly.

The change in the moisture and temperature regimes of the soils studied, induced by the presence of a rye mulch on the soil surface, did not result in significant soybean yield increases or decreases. Delays or decreases in soybean emergence observed for some treatment-years were compensated by the plants as the seasons progressed. If other beneficial aspects of the no-tillage system are considered, such as reduced soil erosion (Phillips et al., 1980), and, weed suppression (Weston, 1990), rye mulch is recommended to be used in no-till soybeans.

Section 3 - MODELLING EXPERIMENTS

3.1. Material and Methods

3.1.1. Crop growth models

Simulation of soybean and rye growth were performed using SOYGRO (Wilkerson et al., 1983; Jones et al., 1989), and CERES-Wheat (Ritchie and Otter, 1985). The computer programs used were versions produced by IBSNAT (International Benchmark Sites Network for Agrotechnological Transfer) (IBSNAT, 1986): IBSNAT/CERES-Wheat V2.10, and IBSNAT/SOYGRO V5.42. To run the models, a Compaq Desk Pro-286 (8 MHz) with a math co-processor was used.

Data necessary to complete the input files containing weather variables, soil parameters, variety genetic coefficients, and experimental conditions were obtained from the rye/soybean experiments performed at Delhi and Woodstock in 1989 and 1990 (Section 2).

Daily values of global solar radiation (MJ/m^2), maximum and minimum air temperatures (C), and rainfall (mm), measured at the experimental sites studied, as well as the weather station's latitude and longitude, were used to prepare weather input files for the models.

The soil input file included in the SOYGRO and CERES-Wheat models contained parameters of standard soil profiles. For this study, a deep sand (Delhi) and a medium loam profile (Woodstock) were chosen from the standard input file, and soil water content at saturation, at the drained upper limit and at the lower limit of plant extractable water (Ritchie, 1981), were estimated from the characteristic curve for the Delhi Fox sand (Van Weesenbeck, pers. comm.), and the Woodstock Guelph loam (measured). For the sandy soil, the drained upper limit of plant extractable water was assumed to occur at 100 cm of water potential and not at field capacity, and the corresponding moisture content was used. For the loam soil, the characteristic curve obtained gave a water content of 0.24 m^3 m^{-3} at the permanent wilting point, assumed as the lower limit of plant extractable water. But, inspection of the lowest water contents measured during July of 1989, when some plant

wilting was observed, suggested that a value of 0.17 m^3 m^{-3} was more adequate. Also, the depth of the original medium loam soil profile was reduced from 1.3 m to 0.9 m, a more common depth for soils in the Woodstock region. Table B.1 contains a listing of the soil input files used.

Other input files needed to run SOYGRO and CERES-Wheat contain experimental information such as plant and row spacing, planting date, and initial soil water content in each soil layer. All these data were presented in Section 2 and the input files are listed in Tables B.4 to B.8. For comparisons between simulated and observed values, files with final yield data and seasonally replicated measured data were also input.

Before the rye and soybean growth models were integrated into a rye mulch/soybean simulation system it was necessary to obtain genetic coefficients for the varieties used, and to verify the accuracy in soil water content predictions under the growing rye in the spring, and under the growing soybeans with no mulch in the summer. Those procedures are described in the following sections, and the related Tables and Figures are in Appendices C, and D and E, respectively.

3.1.1.1. Rye growth modelling

The genetic coefficient file for wheat varieties used in CERES-Wheat contains an extensive list of cultivars used in several parts of the world. The wheat variety Frederick, widely grown in southwestern Ontario, was considered to have similar growth characteristics to the rye plant, and genetic coefficients for this variety were used in the rye growth simulation (Table B.2). Dry matter values measured at Delhi and Woodstock (Section 2) were compared to simulated dry matter accumulation curves.

Comparison of predicted rye dry matter accumulation curves with dry matter observations indicated that CERES-Wheat, including the nitrogen subroutine, underestimated the observed values for the 1989/90 growing season at Delhi and Woodstock (Figure C.1). But, when the nitrogen subroutine was switched off, assuming a non-limiting nitrogen condition, the agreement between

simulated and observed values was improved dramatically (Figure C.2). Therefore, the genetic coefficients for variety Frederick used in CERES-Wheat (N non-limiting) were adequate to be used in a simulation study of rye killing dates.

The agreement between observed and simulated water contents for Delhi and Woodstock in 1988/89 and 1989/90 in the soil layers 0-10 cm, 10-30 cm, and 30-60 cm was satisfactory (Figure C.3, C.4, and C.5), proving that the CERES-Wheat model could be used to simulate the spring soil drying effect due to the growing rye cover crop.

3.1.1.2. Soybean growth modelling

Soybean varieties can be grouped into maturity groups (MG) ranging from 00 to XIII, according to increasing sensitivity to photoperiod and decreasing latitude of adaptation. The genetic coefficient file that describes soybean varieties for the SOYGRO model comprises phenological, vegetative and reproductive growth parameters. For a variety not listed in this input file, general genetic coefficients for maturity groups 00 through X are included (Table B.3), although coefficients for MG 00, I, II, and IV have yet to be tested (Jones et al., 1991). Initially, the coefficients for maturity group 00 were used to run SOYGRO, and results compared to observed values. First, simulated phenological dates were compared to observed dates, and if the simulated dates were not within two days of the observed dates then phenological coefficients were changed to improve this agreement. After the phenological coefficients had been obtained for the varieties studied, fitting of the growth coefficients was performed. Adjustment of all the genetic coefficients was done iteratively by the GENCALC program (Hunt et al., 1992) using the experimental data obtained for the cultivars A1937 and PI-0877 planted at Delhi and Woodstock, respectively. Coefficients were adjusted for each treatment of the experiments conducted at Delhi and Woodstock in 1990. Average coefficients for each variety were then used as inputs to SOYGRO and the predicted soybean variables were compared to the experimental average, since no treatment effect had been

detected. After that, model outputs for the 1989 growing season were compared to the observed values and the validity of the genetic coefficients obtained was evaluated.

The genetic coefficients were defined as follows (Jones et al., 1989):

Phenological coefficients:

- VARTH: days at optimum temperature from the end of the juvenile period to floral initiation under long day conditions divided by the duration of the same period under short days;
- VARNO: shortest night length in which the time taken for floral induction is still at a minimum;
- VARTHR(8): duration (days at optimum temperature and optimum night length) of the period from first flower appearance to the end of expansion of the last leaf;
- VARTHR(10): duration (days at optimum temperature and optimum night length) of the total reproductive period from first flower appearance to physiological maturity.

Vegetative growth coefficients:

- PGLF: maximum rate of single leaf photosynthesis in saturating light for a variety, relative to variety Bragg which would have relative rate of 1;

Reproductive growth coefficients:

- PODVAR: number of pods produced per day with plants growing under short days and at optimum temperatures;
- SHVAR: rate of dry matter accumulation of pods at optimum temperature during the period from half to full size, but before seed growth starts;
- SDVAR: seed filling rate during the linear filling stage and under optimum conditions;
- SDPDVR: mean number of seeds per pod.

The observed variables used to adjust the above described

genetic coefficients were: 1) flowering date (to adjust VARNO and VARTH), 2) physiological maturity (VARTHR(10)), 3) maximum LAI (VARTHR(8)), 3) final canopy biomass (PGLF), 4) number of seeds/m^2 (PODVAR), 5) pod yield (SHVAR), 6) seed yield (SDVAR), 7) number of seeds per pod (SDPDVR).

The remaining genetic coefficients needed to run SOYGRO (Jones et al., 1989) were fixed at the values given for maturity group 00 cultivars (Table B.3).

a) Phenological dates

Emergence date, flowering date and date of physiological maturity were all predicted too late in relation to the observed dates when genetic coefficients for maturity group 00 cultivars were used at Delhi and Woodstock in 1990 (Tables D.1 and D.2). A preliminary fit of flowering date by fixing the photoperiod sensitivity at its minimum (coefficients VARTH and VARNO at the minimum values of 1.5 and 9.5, respectively) resulted in predicted flowering dates that were still too late (4 to 6 days) even if the flowering induction phase (VARTHR(4)) was changed to a minimum of two photothermal days. Furthermore, the difference between simulated and observed emergence dates could only be adjusted by changing the duration from planting to emergence at optimal temperature (VARTHR(1)=5), a coefficient that does not vary among cultivars (Jones et al., 1991). This indicated that the model was underestimating the duration of optimal temperature conditions for vegetative growth at the locations studied. By overpredicting the duration of the vegetative phase from planting to the start of flowering, the modelled flowering date did not match the observed date. The thermal time scale used in SOYGRO is based on work by Hesketh et al. (1973) (Jones et al., 1991), where the optimal temperature for vegetative development is from 30 to 34 C (respectively TOPT1 and TOPT2). It was hypothesized that for varieties adapted to colder climates, like the varieties used in this study, optimal vegetative development might start at temperatures lower than 30 C. Hence, the model was run for several TOPT1 values lower than 30 C, and the simulated emergence date was

compared to the observed date while VARTHR(1) was kept at 5 thermal days. The temperature at which simulated and observed emergence dates at Delhi and Woodstock were closest was then chosen (TOPT1=23 C, Tables D.3 and D.4). With this new TOPT1, the simulated flowering date was also closer to the observed value but simulated and observed maturity dates still differed considerably. Subsequent adjustment of VARTH and VARTHR(10) while fixing VARNO at 9.5, 10.5, or 11.5, resulted in the best agreement between simulated and observed dates at VARNO = 9.5 (Tables D.5 and D.6). The best choice for duration from first flower appearance to physiological maturity at optimal temperature (VARTHR(10)) was within the range given by Jones et al. (1989) (39.1 to 47.5) for cultivar A-1937, but was only 36 photothermal days for cultivar PI-0877. Other genetic coefficients were fixed at the values given in the genetic coefficient file of SOYGRO for cultivars of the maturity group 00 (Jones et al., 1989).

b) Growth and yield

Growth model outputs for initial runs with unadjusted genetic coefficients for maturity group 00 showed that adjustment of vegetative and growth coefficients was necessary (Table D.7 and D.8). Growth and final yields were widely underestimated by SOYGRO in this preliminary run with generic coefficients.

The new genetic coefficients adjusted for variety A-1937 using variables measured in 1990 resulted in growth values that were approximately within one standard deviation of the observed average (of all treatments in Section 2) during both study years, except for final stalk dry matter, which was overestimated by the model (Table D.9). Note that observed seed yields shown were calculated from seed dry matter obtained for 10 plants at harvest maturity.

Agreement between observed and simulated values over time (Figures E.1 to E.4) was close except for an overestimation of canopy growth in 1990, and an overestimation of root growth during both years. Although the observed root dry matter values are probably underestimated, because the sampling was restricted to the

0-30 cm depth, the model estimate of root growth seems excessive. On the other hand, the simulated pod dry matter and pod number increase over time were very close to the measured values during 1990 (Figure E.3D and E.4C).

The new genetic coefficients adjusted for variety PI-0877 for the 1990 growing season at Woodstock resulted in simulated values for many variables that were within one standard deviation of the observed values. Among the exceptions was final stalk dry matter, which was overestimated by the model (Table D.10). In 1989, the predicted maximum leaf area index considerably overestimated the measured value, but the measurement schedule for the leaf area index could have missed the maximum value. Root and canopy growth over time were overestimated at Woodstock, during both study years, although the predicted final above-ground biomass in 1990 agreed well with the observed value (Figure E.5 to E.8). Also, the simulated pod dry matter and pod number increase over time matched the measured values well (Figure E.7D and E.8C).

The general agreement between observed and simulated growth variables, and the particularly good estimates of the important pod yield variables for soybean cultivars A1937 and PI-0877 indicated that the SOYGRO model run with the genetic coefficients here obtained was adequate for use in the simulation of soybean growth in a rye/soybean system.

c) Soil water content

Generally, the submodel WATBAL resulted in good agreement between simulated and observed values for all layers on unmulched soil in Delhi 1989 and 1990 (Figures E.9A, E.9B, E.10A, E.10B, E.11A, and E.11B). At Woodstock the model predictions for the unmulched 30-60 cm layer underestimated measured values in 1990 (Figure E.11E). Soil water contents observed for this layer in 1989 are not shown due to the measurement problems mentioned in Section 2.

3.1.2. Modelling of mulch effects on soil water content

The water balance model WATBAL used in SOYGRO considers that precipitation, runoff, drainage, plant transpiration, and soil

evaporation cause the time-changes in soil water content (Ritchie, 1985). To adapt WATBAL and model the soil water content under a mulch layer, it was assumed that the presence of a mulch on the soil surface affected the soil evaporation and intercepted some of the precipitation available for infiltration.

Rainfall interception by the mulch layer was assumed to occur until the straw reached saturation. The equation added to WATBAL was:

$$DMINT = PCOV*DMSAT*DMUL - DMW \quad [3.1]$$

where DMINT (mm) is rainfall intercepted by the mulch layer, PCOV is fraction of ground covered by mulch, DMUL is mulch dry matter (Mg ha^{-1}), DMSAT is mulch water content at saturation (0.45 mm Mg^{-1} ha^{-1}), and DMW is mulch water content (mm). No data for initial mulch water content was available, and since killing of the rye cover crop had a desiccating effect, it was arbitrarily assumed that initial mulch water content was zero. Rainfall intercepted by the mulch layer was added to this initial mulch water content, while mulch evaporation (EM) was subtracted, that is:

$$DMW = DMW(N-1) + DMINT - EM \quad [3.2]$$

where N is time in days. Mulch evaporation was assumed to occur at the potential evaporation rate, and calculation of EM will be explained later in the text. With this approach it was considered that rainfall in contact with the mulch layer would promptly be absorbed by the straw at first, and would run off or percolate onto the soil surface to infiltrate only after straw saturation was reached. Mulch water content was likely underestimated because of these assumptions because evaporation probably did not occur at the potential rate after some straw drying had occurred, and initial mulch water content was probably not zero. Also, not all rainfall coming in contact with the rye mulch was instantly absorbed, but probably bounced off some straw elements and was readily absorbed

by the soil surface. Hence, DMINT estimates the maximum possible rainfall interception by a mulch layer. For comparison purposes, a second rainfall interception value was calculated by decreasing this maximum mulch interception to 50% of the expression PCOV*DMSAT*DMUL in equation [3.1].

In WATBAL, daily soil water evaporation is calculated in two stages, a constant and a falling rate stage (Ritchie, 1972). In the constant rate stage (stage 1), the soil is sufficiently wet for the water to be transported to the surface at a rate at least equal to the evaporation potential. In the falling rate stage (stage 2), the surface soil water content has decreased below a threshold value, so that the soil evaporation depends on the flux of water through the upper layer of soil to the evaporating site near the surface. When accounting for the effect of a mulch layer on soil evaporation, two aspects of stage 1 evaporation were considered. First, the equilibrium evapotranspiration, as defined by Priestley and Taylor (1972), and used to estimate stage 1 evaporation, was affected through the change in surface albedo caused by the mulch. The relationships between percentage ground cover and albedo, and the change in albedo over time (Wagner Riddle, 1992) were used to obtain the following expression for surface albedo (ALBSFC):

$$ALBSFC = WSAC + (BSAC-WSAC)\exp(-0.047*N) \qquad [3.3]$$

where WSAC and BSAC are, respectively, the albedo for a surface with weathered and bright straw at the current percentage cover, and N is days after mulch placement on the soil surface. This equation is the same as equation [2.8], but adapted to be used at any percentage ground cover. An example of the series of curves obtained for surface albedo at different times after mulch placement on the soil surface, and as a function of percentage ground cover is given in Figure 3.1. The withered and bright straw albedo were calculated as a function of fractional ground cover using:

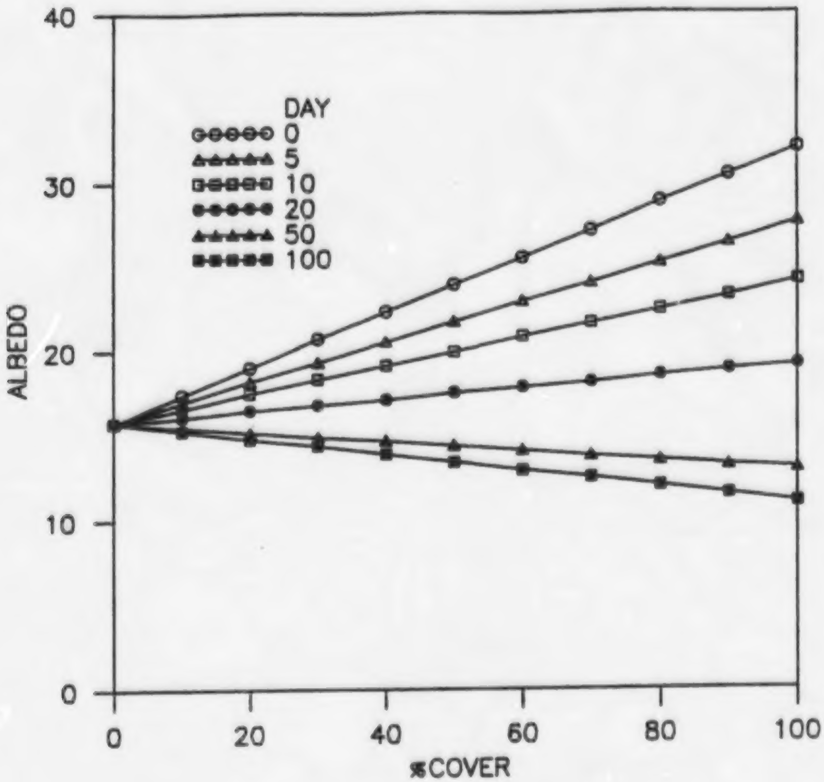

Figure 3.1 - Simulated albedo as a function of percentage ground cover and days after mulch placement on the surface of soil with albedo of 15.8%.

$$WSAC = (1-PCOV)*SALB + PCOV*WSA \quad [3.4]$$

and

$$BSAC = (1-PCOV)*SALB + PCOV*BSA \quad [3.5]$$

where WSA=0.11 and BSA=0.32 are the albedos for a surface with withered and bright straw at 100% ground cover, respectively, and SALB is the soil albedo. PCOV is the fraction of ground cover calculated as a function of mulch dry matter (DMUL) in Mg ha^{-1}:

$$PCOV = 1 - \exp(-A_m*DMUL) \quad [3.6]$$

where the coefficient A_m is the area of mulch per unit mass. A_m was calculated using an equation derived by Wagner Riddle (1992):

$$A_m = A_mI - (A_mF - A_mI)\exp(-0.0474*N) \quad [3.7]$$

where A_mI and A_mF are initial and final values for A_m, 0.55 and 1.08 ha Mg^{-1} respectively, and N is time in days after mulch placement.

The mulch dry matter present on the soil surface at the start of the experiment (DMULCH) was input into the model, and was reduced daily using a mulch reduction rate (Wagner Riddle, 1992), to give a current mulch amount (DMUL) in Mg ha^{-1}:

$$DMUL = DMULCH - DMULCH*0.008*N \quad [3.8]$$

where N is days after mulch placement on the soil surface. A new fractional ground cover was then calculated using [3.6].

The equation in WATBAL for the surface albedo, including plant cover, was then rewritten by replacing the soil albedo with the new composite soil-straw albedo (ALBSFC), that is:

$$ALBEDO = PALB - (PALB - ALBSFC)*\exp(-0.75*XHLAI) \quad [3.9]$$

where PALB=0.23 is the albedo of a closed plant surface, and XHLAI

is the leaf area index.

The second effect of a mulch layer on soil evaporation considered was the reduction in stage 1 evaporation due to restrictions in radiation transmission or diffusion through the mulch. Two approaches were taken: 1) an empirical equation obtained by Steiner (1989) was tried, and 2) the reduction in energy available for soil evaporation due to interception of solar radiation by the mulch layer was considered. Both approaches were limited to stage 1 evaporation, thus are conservative estimates of the effect of a mulch layer on the soil water balance. Steiner's equation relates relative stage 1 evaporation to wheat residue biomass, that is:

$$E1REL = 1.5 - 0.2*\ln(DMUL*100) \qquad [3.10]$$

where E1REL is the ratio between stage 1 evaporation under mulched soil and stage 1 evaporation under bare soil, and DMUL is mulch dry matter (Mg ha^{-1}). The relative stage 1 evaporation (E1REL), calculated using the above equation was then used as a multiplier to the stage 1 soil evaporation calculation in the original WATBAL subroutine.

In the solar radiation interception approach it was considered that only the fraction of solar radiation transmitted through the mulch layer would be available for the stage 1 soil evaporation. The transmittance (TRANS) was calculated as a function of residue area index (RAI) using an equation obtained by Wagner Riddle, 1992:

$$TRANS = \exp(-0.98*RAI) \qquad [3.11]$$

The RAI was estimated from the mulch dry matter through:

$$RAI = A_m*DMUL \qquad [3.12]$$

where symbols are same as above. The potential soil evaporation

calculated in the original WATBAL model was then reduced through multiplication by TRANS.

Mulch potential evaporation was estimated as the equilibrium evaporation (Priestley and Taylor, 1972) multiplied by (1-TRANS) to account for the solar radiation intercepted by the mulch.

To evaluate the effectiveness of the two approaches described in predicting soil water content under a mulch surface, the changed WATBAL subroutines (WATBAL1 with equation [3.10] and WATBAL2 with equation [3.11]) were run for two mulch loads, 2.8 and 8.5 Mg ha^{-1}. Water uptake by plants was set to zero so that the effect of the mulch on soil evaporation could be isolated from the plant transpiration process. The model results were then compared to volumetric soil water contents measured under those two mulch loads during 1990 at Delhi in experimental plots with no growing soybean plants (Wagner Riddle, 1992).

3.1.3. Modelling of mulch effect on soybean yield

After selecting the best approach to simulate the soil water balance under a mulch, the model was run for two mulch amounts, corresponding to rye dry matter values obtained through an early and late rye killing date (Section 2), during the soybean growing seasons of 1989 and 1990, at Delhi and Woodstock. The rye dry matter amounts present on the soil surface at soybean planting time were included in the input file with treatment management information (Table D.5, lines 1,3 and 5, column 4). Soil water contents and soybean yields had been measured for the two mulch treatments and were used to evaluate the model output. The objective was to test if the modelled effect of the rye mulch on soil water content in a situation with growing soybean plants was realistic, and if the model predicted only small differences in soybean yield due to the presence of a mulch, as were observed (Section 2).

3.1.4. Weather scenarios for the simulations of the rye/soybean system

The soil water depletion by the growing rye, followed by the rye mulch effect on soybean growth, were simulated under several

hypothetical rainfall conditions for Delhi and Woodstock during 1989 and 1990.

Rye growth was simulated using CERES-Wheat and the input files consisting of data measured at the experimental sites (Section 2). To maximize the effect of soil water depletion due to the growing rye, two rye killing dates close to soybean planting time were selected for each location-year. One killing date selected corresponded to the late killing date used in the field experiments, approximately 1 week before soybean planting (Section 2), and the other killing date was just before soybean planting time. It was assumed that killing and mowing were performed on the same date. The earlier killing dates were May 24, 1989 and May 15, 1990 for Woodstock, and May 19, 1989 and May 14, 1990 for Delhi. The later rye killing dates were May 29, 1989 and June 1, 1990, for Woodstock, and May 23, 1989 and May 21, 1990, for Delhi. CERES-Wheat model outputs of canopy dry matter and soil profile water content on those dates under the selected rainfall scenarios were input into SOYGRO, as mulch amount and initial soil water conditions, respectively. The control treatment in the soybean simulation experiment was rye ploughed under on May 1, 1989 and 1990. Soil water content predicted by the CERES model on May 1 was used as initial conditions for the ploughed treatment in SOYGRO. The water balance subroutine was initiated on the date of killing and mowing, and on the ploughing date. On the other hand, soybean growth simulation started on soybean planting date, which was the same as used during the field experiments.

The selected weather scenarios are described in Table 3.1, and consisted mainly of combinations of wet and dry months. Since the weather observed at Delhi and Woodstock consisted of an adequate rainfall distribution for the months of May through July, except for July of 1989 (Figures 3.2 and 3.3, Table 3.3), dry weather scenarios were constructed by taking data measured for a certain month and eliminating days with rainfall, as listed on Table 3.1 and 3.2 for Delhi and Woodstock, respectively. The average reduction of total monthly rainfall from the "wet" to the "dry"

Table 3.1 - Description of weather scenarios used in simulation of rye mulch effect on soybean growth in Delhi. Rainfall recorded on the days listed for each scenario was changed to zero. The "wet" scenario refers to the observed rainfall.

Delhi 1989	Days with altered rainfall
wet May/wet June	none
wet May/dry June	June 7-9,12-23
dry May/wet June	May 4,5,7,8,10-12,23,24-26,30-31
dry May/dry June	May 4,5,7,8,10-12,23,24-26,30-31 June 7-9,12-23
Delhi 1990	
wet May/wet June	none
wet May/dry June	June 2-4,18,19,22,23
wet May/dry June+July	June 2-4,18,19,22,23 July 8,9,11,12
dry May/wet June	May 10-21,27-30
dry May/dry June	May 10-21,27-30 June 2-4,18,19,22,23
dry May/dry June+July	May 10-21,27-30 June 2-4,18,19,22,23 July 8,9,11,12

Table 3.2 - Description of weather scenarios used in simulation of rye mulch effect on soybean growth in Woodstock. Rainfall recorded on the days listed for each scenario was changed to zero. The "wet" scenario refers to the observed rainfall.

Woodstock 1989	Days with altered rainfall
wet May/wet June	none
wet May/dry June	June 8,10,12,16,17,19-22,24
dry May/wet June	May 5,7,10-12,20,23,25,26,29-31
dry May/dry June	May 5,7,10-12,20,23,25,26,29-31 June 8,10,12,16,17,19-22,24
Woodstock 1990	
wet May/wet June	none
wet May/dry June	June 3,8,22-24,26
wet May/dry June+July	June 3,8,22-24,26 July 8,9,12,14-20
dry May/wet June	May 10-13,15-20,29
dry May/dry June	May 10-13,15-20,29 June 3,8,22-24,26
dry May/dry June+July	May 10-13,15-20,29 June 3,8,22-24,26 July 8,9,12,14-20

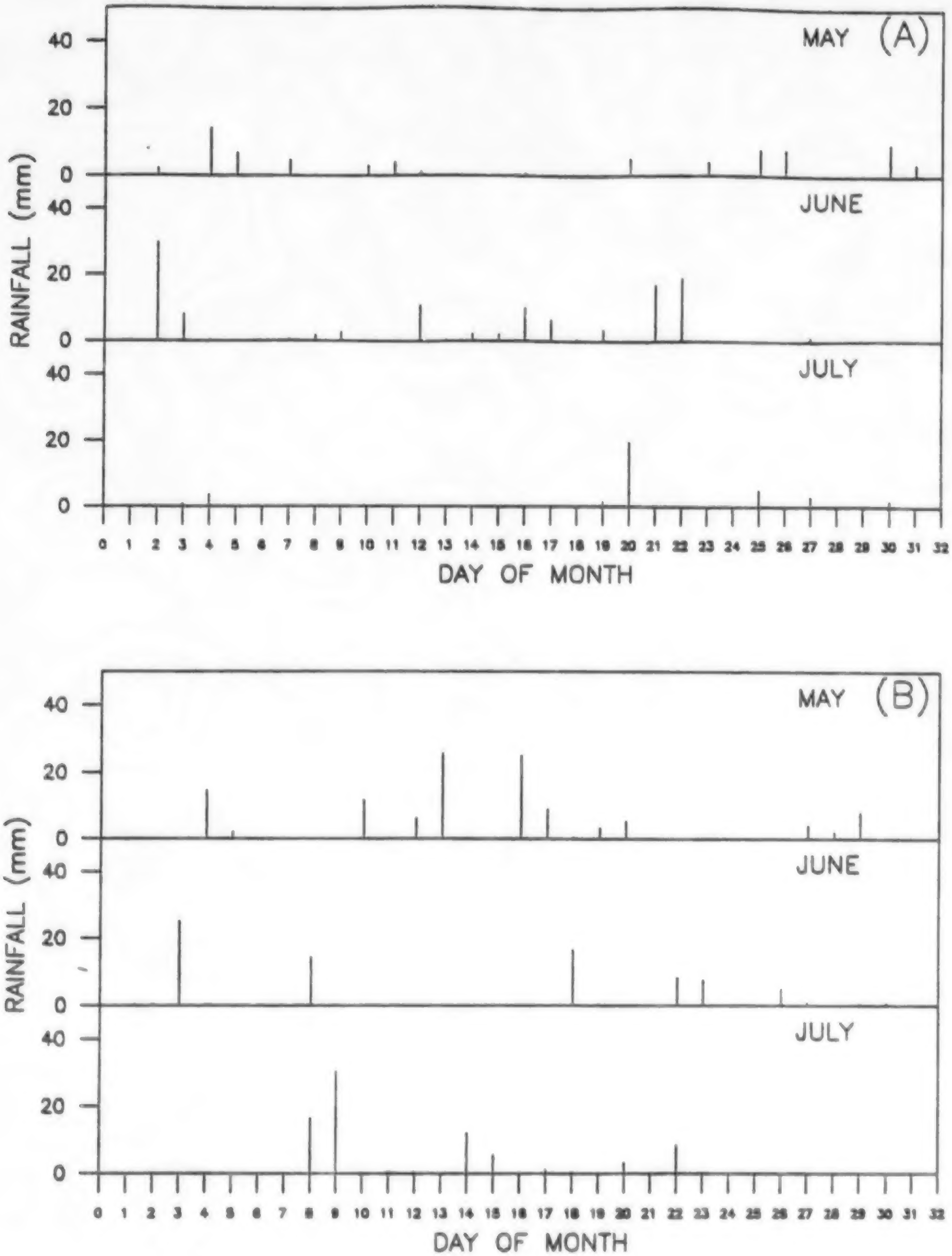

Figure 3.2 - Daily rainfall recorded at Delhi during the months of May, June, and July of (A) 1989 and (B) 1990.

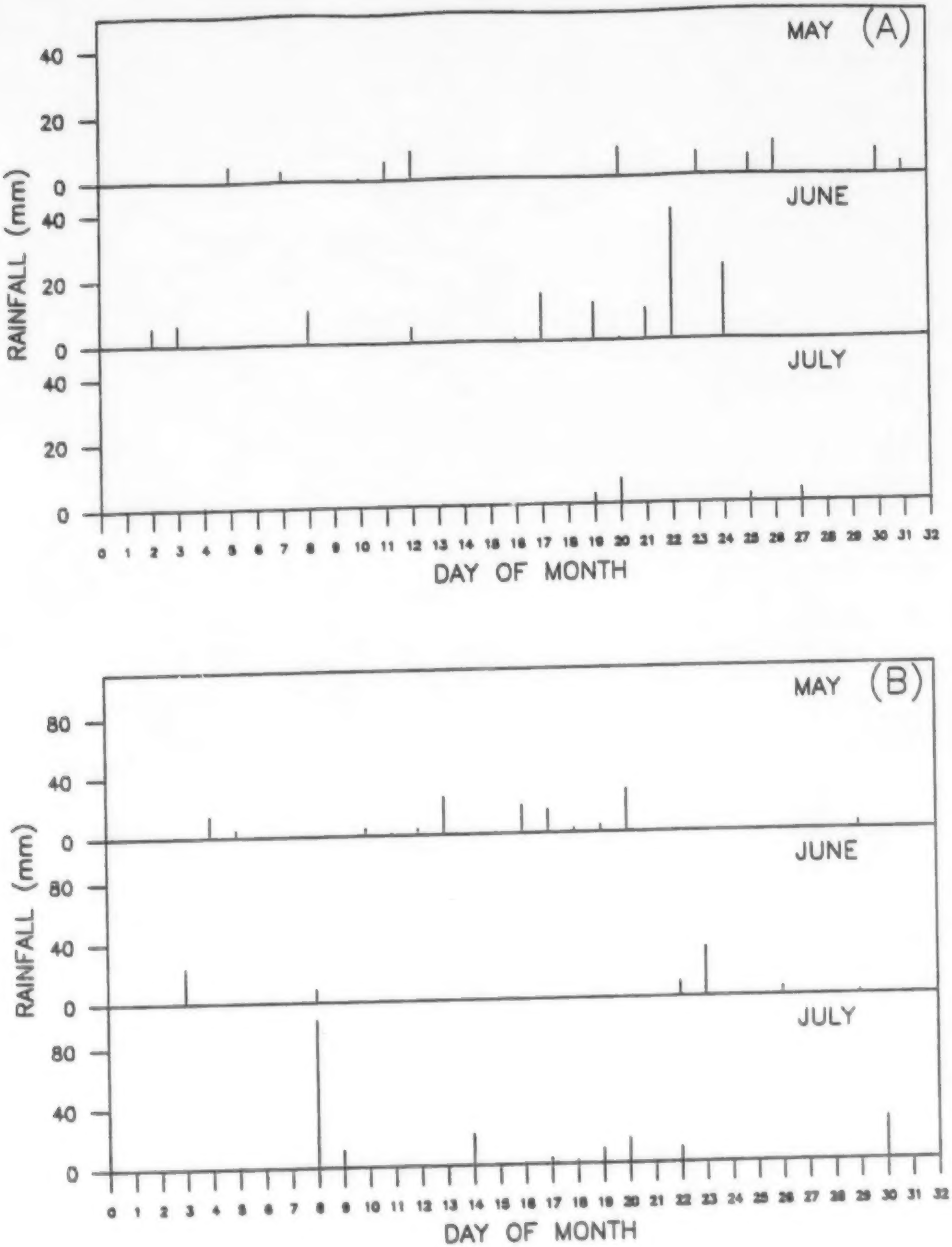

Figure 3.3 - Daily rainfall recorded at Woodstock during the months of May, June, and July of (A) 1989 and (B) 1990.

Table 3.3 - Total monthly rainfall for weather scenarios used in simulations of rye mulch effect on soybean growth at Delhi and Woodstock during 1989 and 1990. The "wet" scenario represents the actual rainfall at these location-years.

Location	Year	Month	Rainfall (mm)		
			wet	dry	normal[$]
Delhi	1989	May	72.8	7.8	73 ± 32
		June	114.6	39.4	71 ± 34
		July	34.6	-	71 ± 26
	1990	May	119.4	16.6	-
		June	80.8	7.4	-
		July	79.2	31.0	-
Woodstock	1989	May	65.0	0.4	65 ± 26
		June	125.8	12.4	82 ± 37
		July	16.8	-	75 ± 32
	1990	May	130.2	19.0	-
		June	82.8	7.4	-
		July	203.2	38.4	-

[$] total and standard deviation (1951-1980)

scenario was 90% (Table 3.3).

For each weather scenario of Table 3.1, the complete rye/soybean model was run for the early killing, late killing and ploughed treatment. Simulated soybean yields were obtained for each treatment under the selected rainfall patterns and compared.

3.2. Results and Discussion

3.2.1. Modelling of mulch effects on soil water content

The output of a model run with no growing plants or mulch corrections is compared to soil water content measured in a mulch experiment with no growing plants at Delhi during 1990 (Figure 3.4). The graphs on the right side and left side in Figure 3.4 show, respectively, data measured at depths 0-5 cm and 5-10 cm. From top to bottom in Figure 3.4, the model outputs using the WATBAL subroutine are compared to soil water content measured under no-mulch (Figures 3.4A and 3.4B), under 2.8 Mg ha^{-1} of rye mulch (Figures 3.4C and 3.4D), and under 8.5 Mg ha^{-1} of rye mulch (Figures 3.4E and 3.4F). The simulated values were lower than the observed values for both mulch rates, specially at the 0-5 cm depth (Figures 3.4C and 3.4E), showing the need for a characterization of the mulch effect on the water balance processes in WATBAL.

The use of equations [3.1], [3.2] and [3.10], respectively describing the rainfall interception by the mulch, the effect of a rye mulch on the surface albedo and soil water evaporation (Steiner, 1989), resulted in a decrease in the difference between simulated and observed soil water contents under the mulched treatments at both depths (Figure 3.5). A linear regression between observed and simulated values had correlation coefficients of 0.56 and 0.50, and slopes of 0.85 and 0.94, for the early and late killing treatment, respectively. But the changed subroutine (WATBAL1), showed drying of the surface layer that was too fast when compared to the observed values.

The second approach used (WATBAL2), that is the reduction in soil evaporation due to interception of solar radiation by the mulch (equations [3.11] and [3.12]), yielded good agreement between

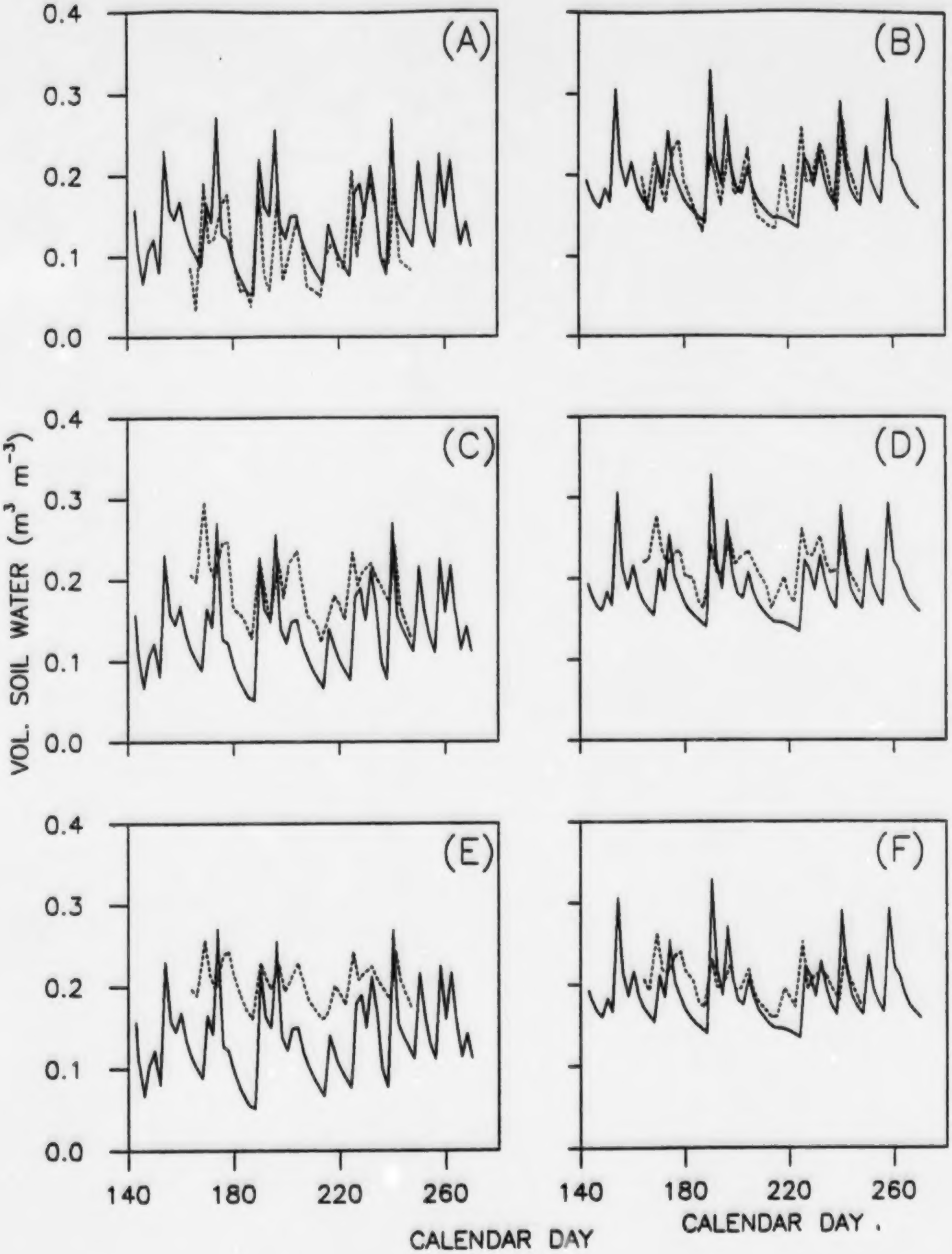

Figure 3.4 - Volumetric soil water content simulated (solid line) using SOYGRO with no plant water uptake, versus observed values (dotted line) at Delhi in 1990 for no-mulch at (A) 0-5 cm and (B) 5-10 cm; for mulch rate of 2.8 Mg ha^{-1} at (C) 0-5 cm and (D) 5-10 cm; and for mulch rate of 8.5 Mg ha^{-1} at (E) 0-5 cm and (F) 5-10 cm depth.

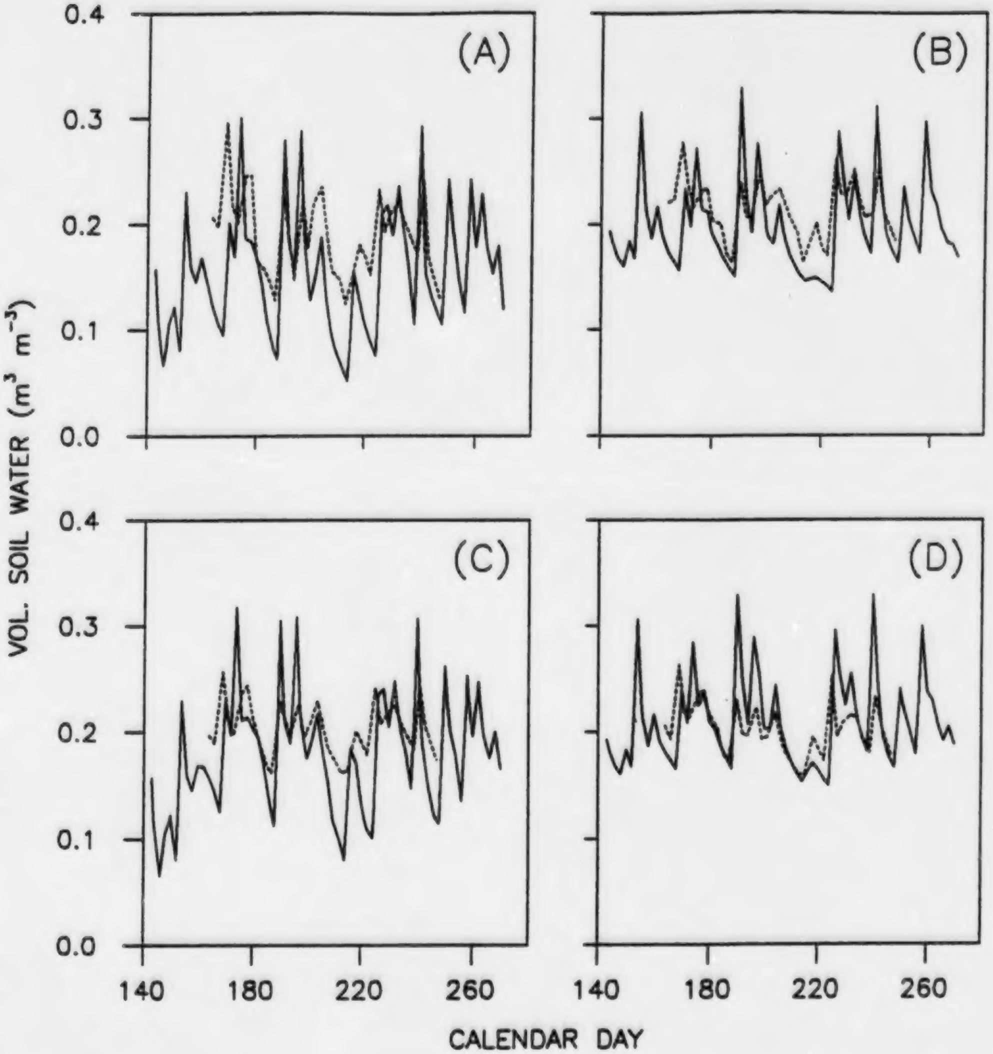

Figure 3.5 - Volumetric soil water content simulated (solid line) using WATBAL1 (Steiner's equation) in SOYGRO with no plant water uptake, versus observed values (dotted line) at Delhi in 1990 for mulch rate of 2.8 Mg ha^{-1} at (A) 0-5 cm and (B) 5-10 cm; and for mulch rate of 8.5 Mg ha^{-1} at (C) 0-5 cm and (D) 5-10 cm depth.

measured and simulated water contents for the lower mulch rate (Figures 3.6A and 3.6B). The r^2 value and slope between observed and predicted values were 0.56 and 1.01, respectively, But, the higher mulch rate produced soil evaporation rates close to zero, and consequently the simulated soil water content was too high (r^2=0.40, slope=1.12). This was likely caused by an overestimation of radiation intercepted by the mulch since equation [3.11] combined with equation [3.12] predicted transmittance values of the order of 0.01. Scaling of the solar energy available for potential soil evaporation by use of the transmittance alone, therefore resulted in little or no simulated energy available under the heavy mulch. If the occurrence of energy pathways such as multiple reflection and transmittance through residue elements (i.e. elements not completely black) had been considered, the potential soil evaporation under a heavy mulch would have increased. Therefore, it was arbitrarily assumed that a minimum of 10% of intercepted solar energy was available for the process of soil water evaporation and a lower limit of 0.10 for the transmittance was set. The model output for the water balance subroutine with this lower limit of transmittance (WATBAL3) showed better agreement (r^2=0.54, and slope=1.04 for late killing date, Figure 3.7). These results demonstrated that the mulch effect on the soil water content was simulated better by the reduction in soil evaporation using equations described here as opposed to Steiner's model, and hence SOYGRO with WATBAL3 could be used to simulate the effect of rye mulch on soybean growth.

3.2.2. Modelling of mulch effects on soybean yields

The next step was then to verify the yield predictions for soybeans grown under two rye mulch amounts, corresponding to the early and late rye cover crop killing treatments described in Section 2. The model overpredicted final above-ground biomass by approximately two standard deviations in 50% of the location-years studied, but the more important simulated seed yields were within one standard deviation of the observed mean values (Table 3.4). Also, the simulated effect of the rye mulch on soil water content

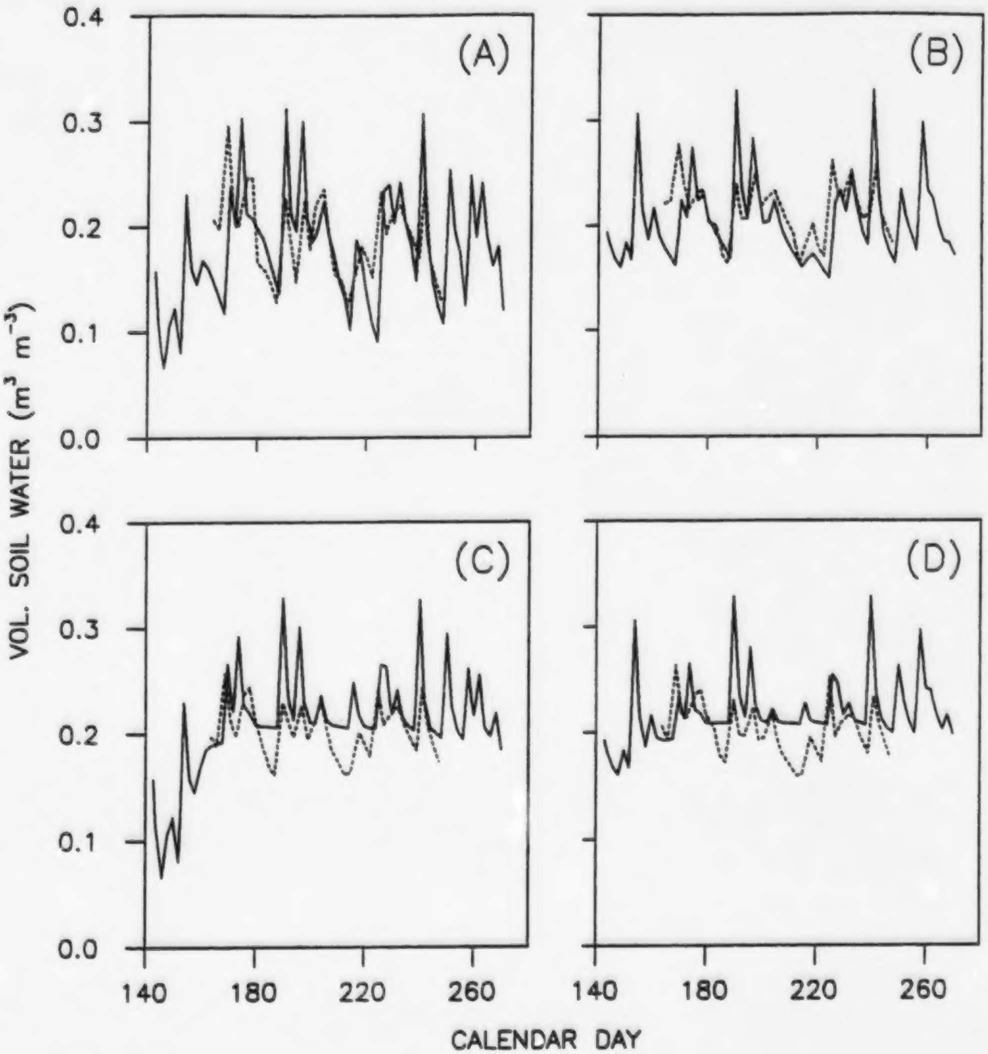

Figure 3.6 - Volumetric soil water content simulated (solid line) using WATBAL2 (no lower limit for transmittance) in SOYGRO with no plant water uptake, versus observed values (dotted line) at Delhi in 1990 for mulch rate of 2.8 Mg ha^{-1} at (A) 0-5 cm and (B) 5-10 cm; and for mulch rate of 8.5 Mg ha^{-1} at (C) 0-5 cm and (D) 5-10 cm depth.

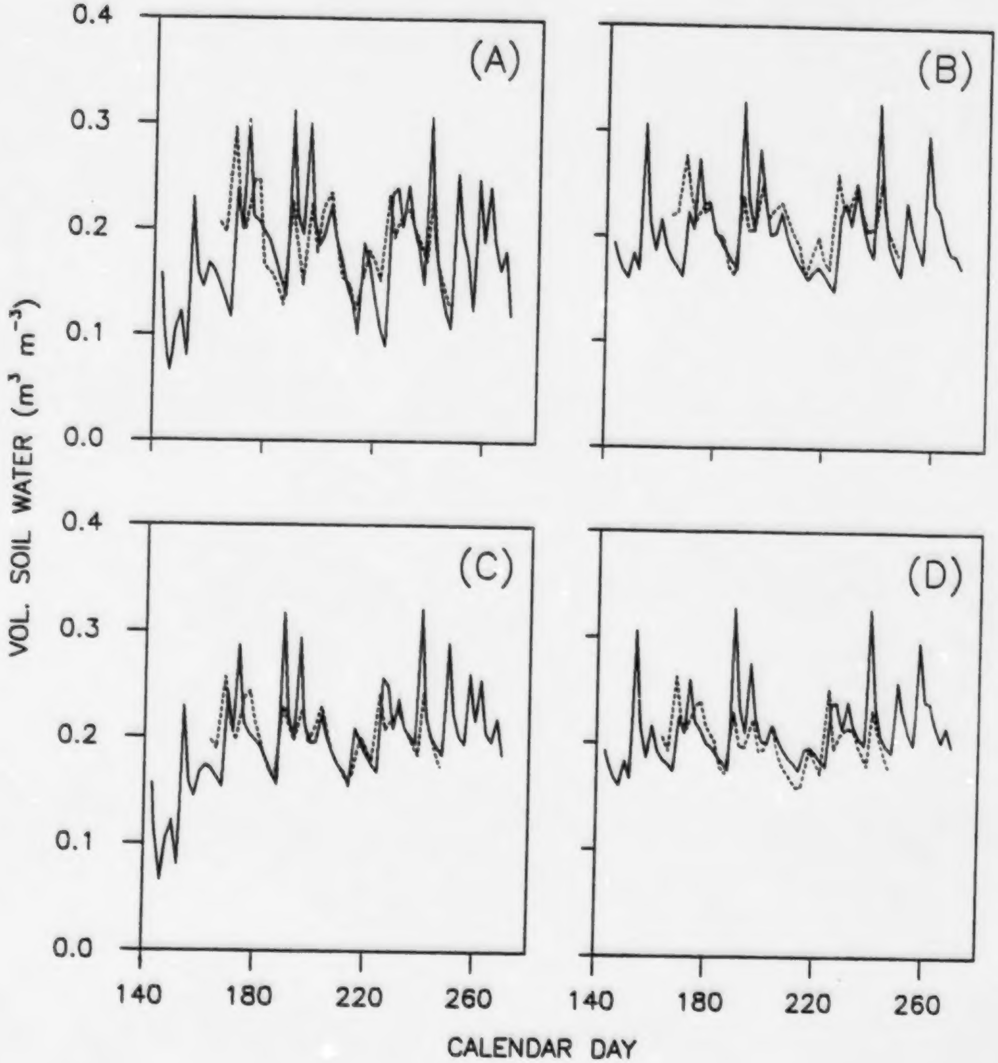

Figure 3.7 - Volumetric soil water content simulated (solid line) using WATBAL3 (lower limit for transmittance of 10%) in SOYGRO with no plant water uptake, versus observed values (dotted line) at Delhi in 1990 for mulch rate of 2.8 Mg ha^{-1} at (A) 0-5 cm and (B) 5-10 cm; and for mulch rate of 8.5 Mg ha^{-1} at (C) 0-5 cm and (D) 5-10 cm depth.

Table 3.4 - Comparison between observed and simulated seed and final biomass yields for mulched treatments at Delhi and Woodstock in 1989 and 1990. Two mulch amounts shown are for early and late killing date treatments.

Location	Year	Mulch dry matter ($Mg\ ha^{-1}$)	Seed yield ($Mg\ ha^{-1}$)		Final biomass ($Mg\ ha^{-1}$)	
			model	observed#	model	observed*
Delhi	1989	1.5	2.6	2.1 0.53	4.5	3.4 0.84
		2.1	2.7	2.2 0.66	4.6	3.7 1.1
	1990	2.2	4.4	4.5 0.94	8.3	7.3 1.6
		3.5	4.4	3.7 0.69	8.2	5.9 1.2
Woodstock	1989	2.3*	3.8	3.2 0.83	7.0	5.1 1.4
		2.9	4.1	3.3 0.77	7.2	5.2 1.1
	1990	3.5	4.5	4.4 0.87	7.9	7.0 1.3
		4.8	4.4	5.1 0.58	7.8	8.0 0.90

* mulch dry matter for early and late killing dates includes 1.7 Mg ha^{-1} of residue from previous soybean crop.
# treatment average and standard deviation.

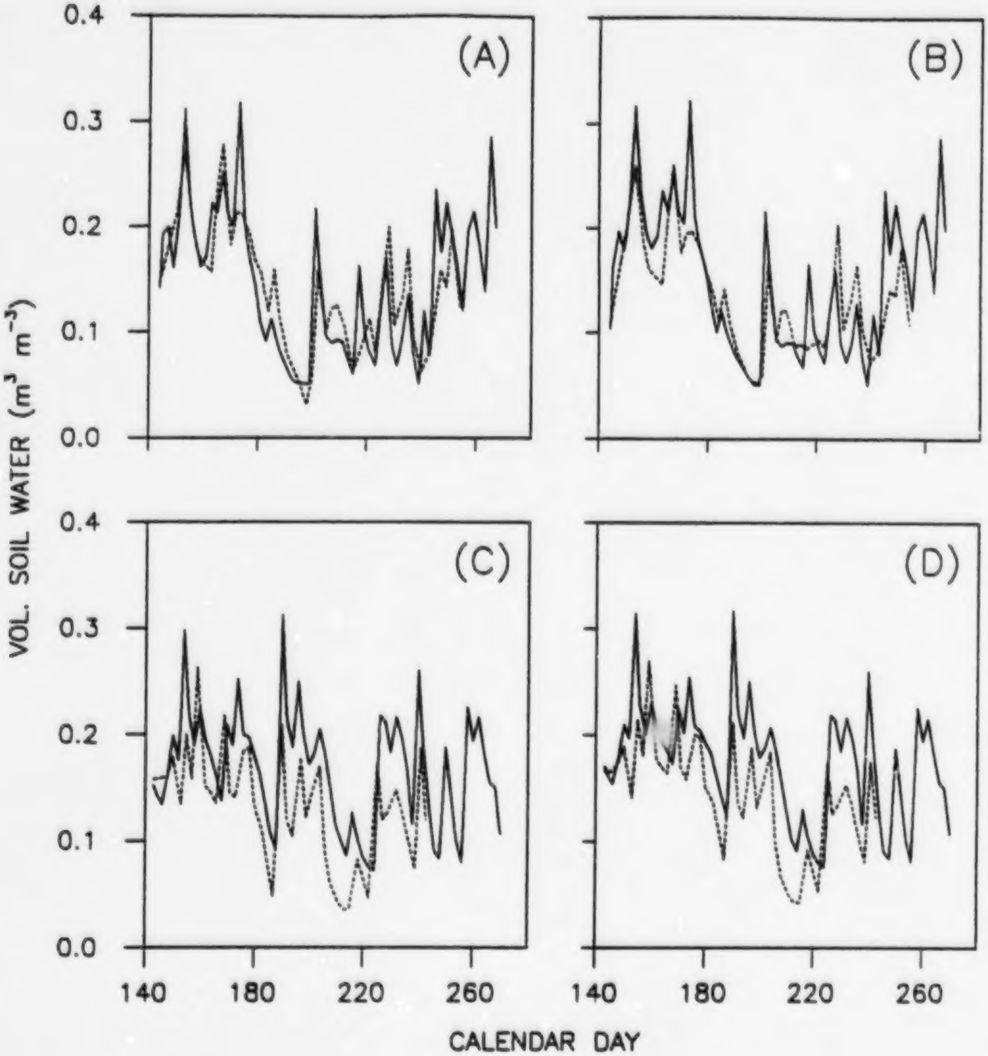

Figure 3.8 - Volumetric soil water content simulated (solid line) for the 0-10 cm layer using WATBAL3 (lower limit for transmittance of 10%) in SOYGRO with plant water uptake, versus observed values (dotted line) at Delhi in 1989 for mulch rates of (A) 1.5 Mg ha^{-1} and (B) 2.1 Mg ha^{-1}; and in 1990 for mulch rates of (C) 2.2 Mg ha^{-1} and (D) 3.5 Mg ha^{-1}.

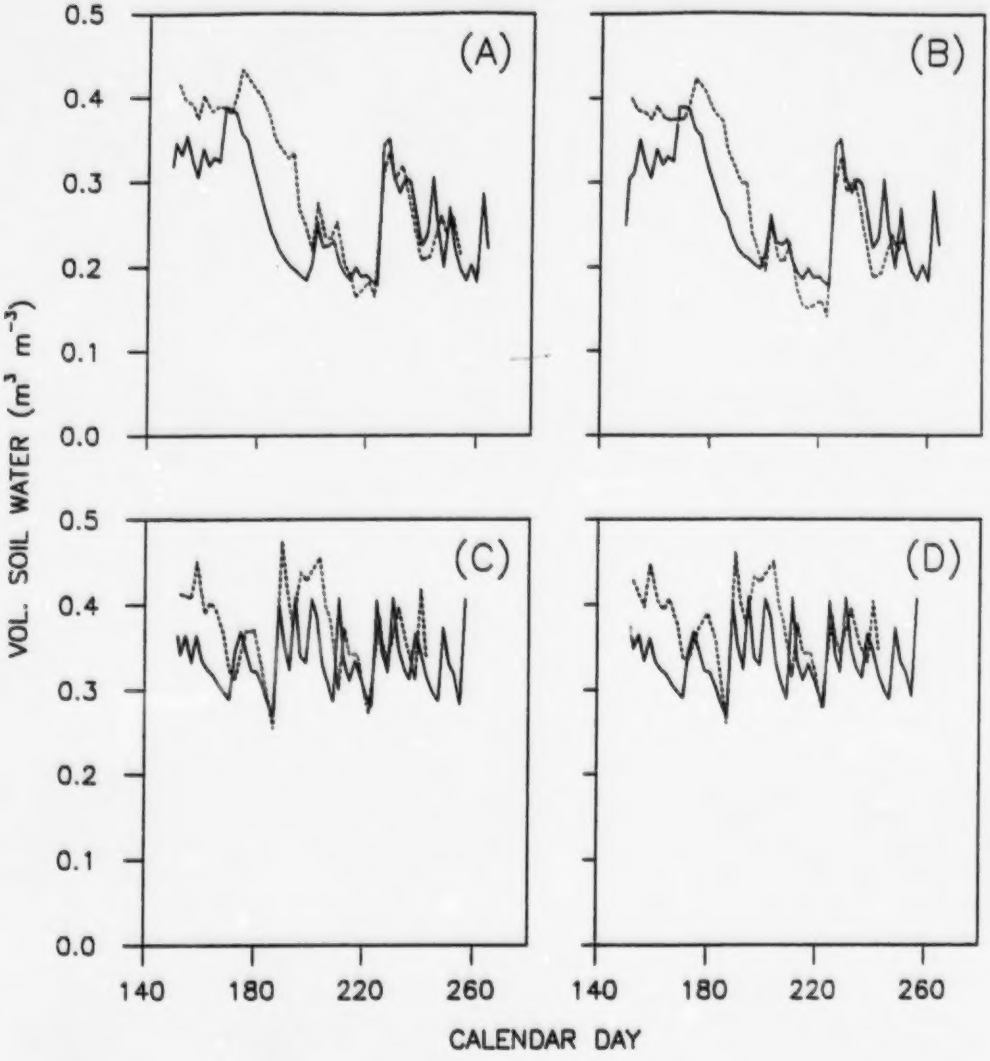

Figure 3.9 - Volumetric soil water content simulated (solid line) for the 0-10 cm layer using WATBAL3 (lower limit for transmittance of 10%) in SOYGRO with plant water uptake, versus observed values (dotted line) at Woodstock in 1989 for mulch rates of (A) 2.3 Mg ha^{-1} and (B) 2.9 Mg ha^{-1}; and in 1990 for mulch rates of (C) 3.5 Mg ha^{-1} and (D) 4.8 Mg ha^{-1}.

did not result in significant increases in seed yields with an increase in mulch dry matter, just as was observed during field experiments (Section 2). Agreement between simulated and observed soil water contents in the surface layer under the two mulch conditions present in 1989 and in 1990 at Delhi and Woodstock, respectively, was usually close (Figure 3.8 and 3.9). An exception was the first third of the soybean season at Woodstock in 1989 (Figure 3.9A and 3.9B), when residue from the previous soybean crop was present and probably not as effective as the assumed rye mulch in reducing soil evaporation. This lead to an observed soil moisture smaller than the simulated values. Based on these results, it was concluded that the subroutine WATBAL3 was adequate to simulate the effect of rye mulch on soil water content and on the resultant soybean seed yield.

3.2.3. Simulation of the rye/soybean system during various weather scenarios

A maximum of 0.3 Mg ha^{-1} reduction in rye yield was observed due to the simulation of a "dry" month of May (7.8 mm) at Delhi in 1989 (Table 3.5). Rye dry matter production was never affected by decreasing rainfalls at Woodstock (Table 3.6). The simulated soil water contents on two rye killing dates, and a rye ploughing date (May 1), varied with the timing of rainfall events (Table 3.5 and 3.6). Delaying of rye killing resulted in further drying of the soil profile during the "dry" scenario only at the loam soil site (Table 3.6), since the level of soil water content between early and late killing dates was such that water uptake by plants was still possible. But at the sandy soil site (Table 3.5), the soil water content was already close to the lower limit on the early killing date, and delaying of rye killing did not result in further soil drying.

Simulated soybean yields following rye killed early (-2 weeks before soybean planting) under weather conditions observed at the experimental sites ("wet/wet" scenario in Figures 3.10 and 3.11) were similar to the yields simulated using measured rye mulch amounts and initial soil water contents as inputs to SOYGRO

Table 3.5 - Rye dry matter and volumetric soil water content at different depths simulated by CERES-Wheat for two spring weather scenarios at Delhi. Model outputs on two simulated rye killing dates, and on a rye ploughing date are shown.

Scenario[*]	Killing date[$]	Rye dry matter ($Mg\ ha^{-1}$)	Volumetric soil water (%) layer (cm)				
			0-10	10-30	30-45	45-60	60-75
wet May '89	early	2.2	8	12	12	11	10
	late	2.8	12	11	10	10	9
	ploughed	-	12	13	13	13	10
dry May '89	early	2.2	5	9	8	9	9
	late	2.5	5	9	8	8	8
wet May '90	early	4.3	19	18	13	8	8
	late	5.1	19	18	17	16	13
	ploughed	-	5	10	9	10	9
dry May '90	early	4.3	6	9	7	8	8
	late	5.0	5	8	6	7	7

* description in Table 3.1
$ see text for actual dates

Table 3.6 - Rye dry matter and volumetric soil water content at different depths simulated by CERES-Wheat for two spring weather scenarios at Woodstock. Model outputs on two simulated rye killing dates, and on a rye ploughing date are shown.

Scenario[*]	Killing date[$]	Rye dry matter ($Mg\ ha^{-1}$)	Volumetric soil water (%) layer (cm)				
			0-10	10-30	30-45	45-60	60-75
wet May '89	early	3.3	27	28	27	28	28
	late	4.4	27	28	27	27	27
	ploughed	-	30	30	31	31	32
dry May '89	early	3.3	20	22	24	25	26
	late	4.3	18	20	21	22	22
wet May '90	early	4.6	32	31	29	27	26
	late	7.4	29	30	30	31	31
	ploughed	-	22	25	27	29	29
dry May '90	early	4.6	20	23	25	25	26
	late	7.4	13	19	20	20	20

* description in Table 3.1
$ see text for actual dates

(Section 3.4.4.). Note that SOYGRO had been calibrated using seed yields calculated from seed dry matter obtained from 10 plants sampled at harvest. Therefore, the unusually high yields in 1990 probably overestimated yields that would have been obtained from harvesting larger areas. In any case, differences in mulched aand no mulched soybeans were the main subject of this simulation.

Predicted soybean yields under the mulch treatments at Delhi (Figure 3.10) were increased by approximately 10% when the simulated rainfall interception was decreased by 50% in WATBAL3. Small yield advantages (-0.5 Mg ha^{-1}) were then predicted for the mulched treatments over the no mulch treatment, during "wet/wet", "wet/dry", and "wet/dry/dry" scenarios (Figures 3.10, raw data in Table D.11). These differences were within the standard deviations observed for the treatment means (Tables D.9 and D.10), and indicated that the absence of a significant mulch effect on soybean yields observed during field experiments would have persisted even if the weather conditions had been drier during June and July. However, when drought occurred early in the season (scenario "dry/wet"), mulch amounts that were larger then 4.0 Mg ha^{-1} resulted in soybean yields that were 2.1 Mg ha^{-1} larger than under a no mulch treatment (Figure 3.10B). Apparently, the soil profile was replenished by rainfalls in June, and soil drying was slower under the mulch treatment, presenting better conditions for soybean growth.

Simulation results for Woodstock 1989 (Figure 3.11A and Table D.10) showed that the late rye killing date yielded less if either May or June were dry for either 50% or 100% rainfall interception. This indicated that the lower initial soil water content was carried over the whole season, and that the soil water conservation by the additional rye dry matter accumulated (1.1 Mg ha^{-1} in Table 3.6) did not compensate. In 1990 (Figure 3.11B), the reduction in soil evaporation due to the additional 2.8 Mg ha^{-1} of rye mulch produced from the early to the late killing date compensated the depletion of soil moisture by the growing rye during the "dry" May so no significant yield loss was simulated.

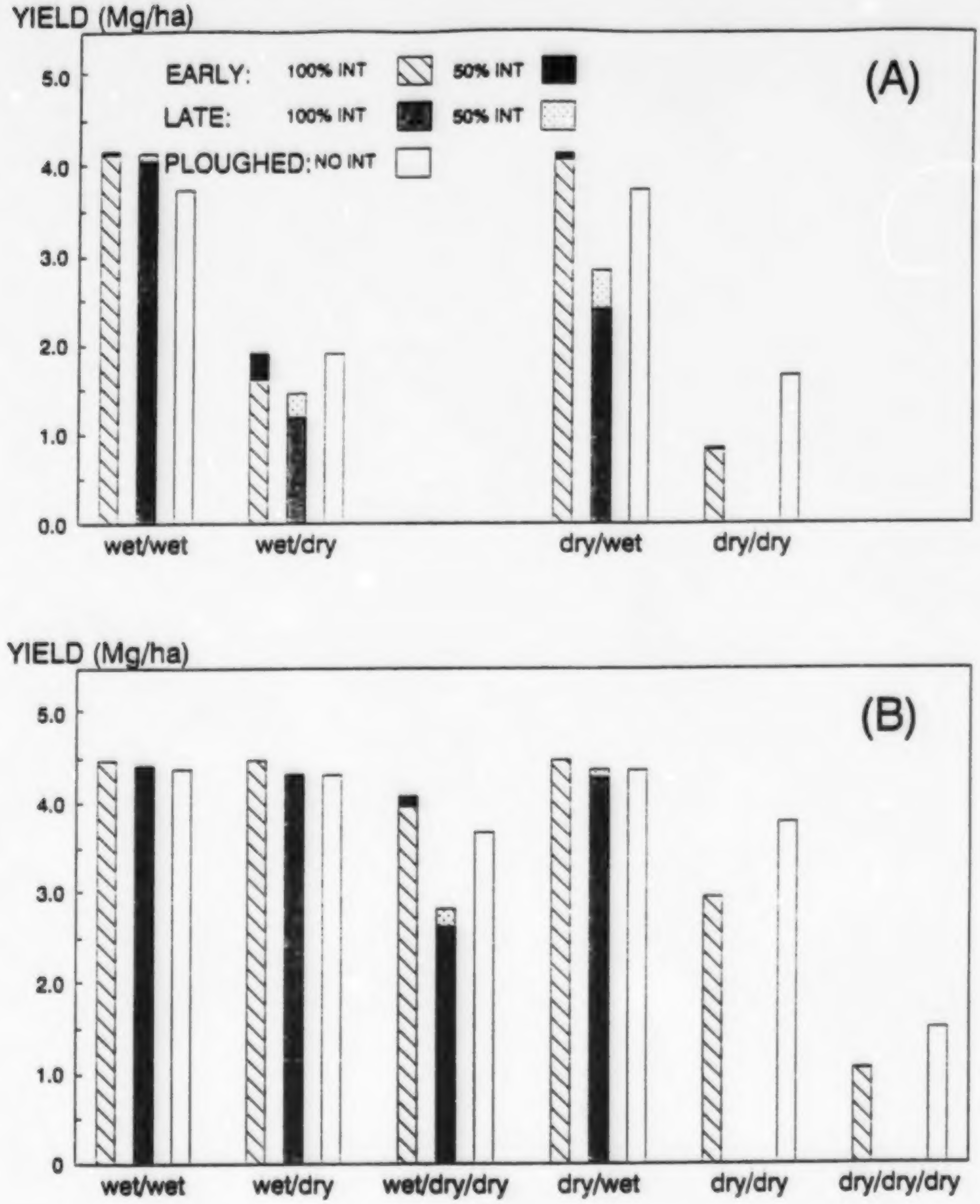

Figure 3.11 - Soybean seed yields simulated for two mulch conditions (early and late rye killing dates) and a ploughed condition under various weather scenarios at Woodstock in (A) 1989 and (B) 1990. For mulch conditions yields are shown for 100% and 50% rainfall interception (INT). See Table 3.1 for explanation of rainfall conditions.

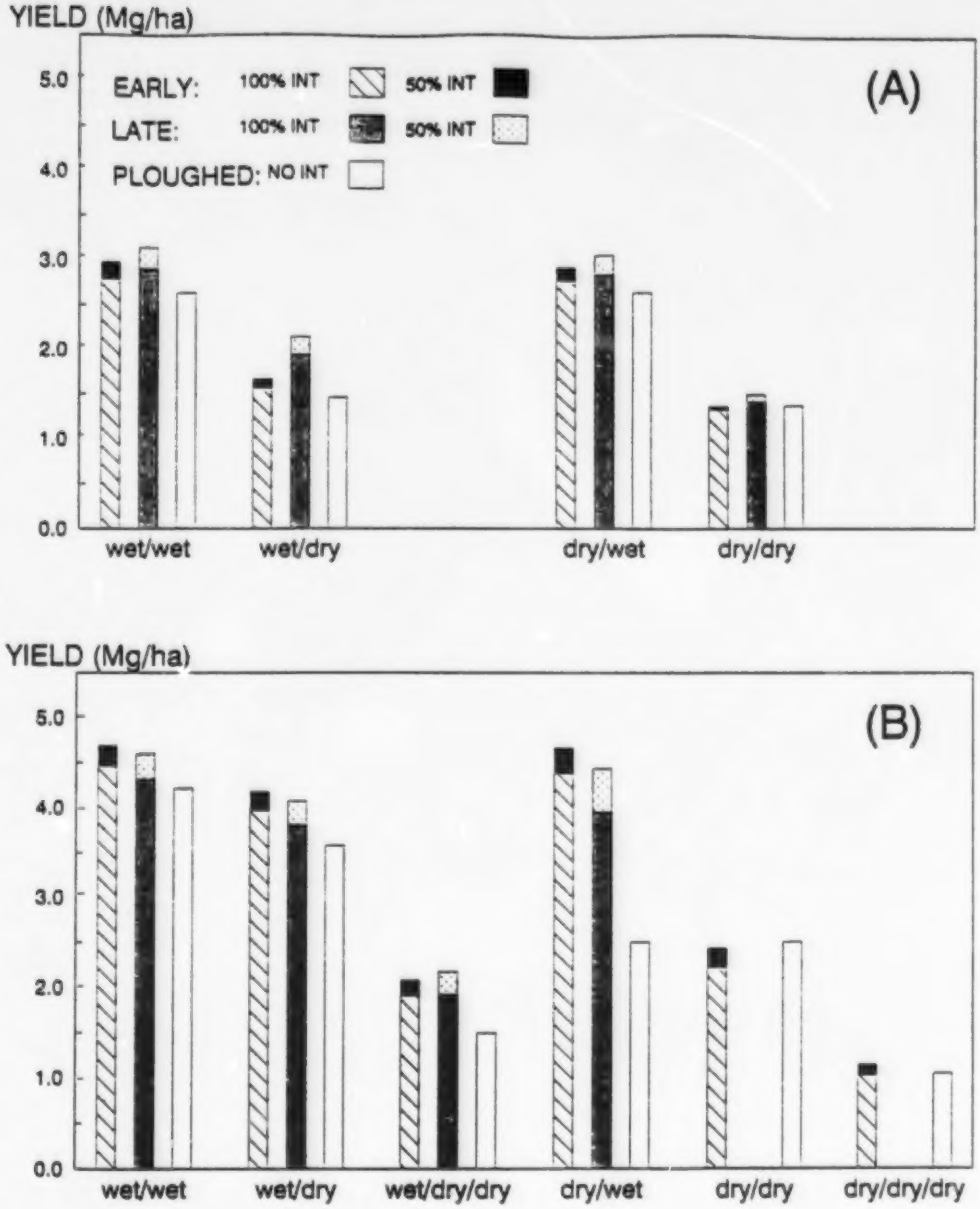

Figure 3.10 - Soybean seed yields simulated for two mulch conditions (early and late rye killing dates) and a ploughed condition under various weather scenarios at Delhi in (A) 1989 and (B) 1990. For mulch conditions yields are shown for 100% and 50% rainfall interception (INT). See Table 3.1 for explanation of rainfall conditions.

At both locations, the extremely dry rainfall conditions ("dry/dry", and "dry/dry/dry") resulted in crop failure due to water stress under the late killing date treatment. The early killing treatment presented similar yields to the no mulch treatment at Delhi in 1990, but somewhat reduced yields (-0.7 Mg ha^{-1}) at Woodstock in 1989 and 1990. But, the probability of occurrence of such low rainfall totals for three consecutive months is very small, and the results obtained for "wet/dry", "wet/dry/dry", and "dry/wet" scenarios are more likely to occur. Killing rye about 1 week before soybean planting is recommended since this treatment showed soybean yield advantages over killing at planting time for at least two weather scenarios at Woodstock. Furthermore, small yield advantages were observed in the simulated soybean yields for the early killing over the no mulch treatment at Delhi, and no crop failure was simulated for the early killing treatment at Delhi and Woodstock even in extremely dry rainfall conditions. Field experiments (Section 2) had shown no difference between early and late killing treatments (3 and 1 week before soybean planting) for observed ("wet" scenario) weather conditions. In this modelling experiment it was shown that additional rye mulch accumulated during the one week before soybean planting was similarly not advantageous when the observed weather conditions were used in the simulation. However, soybean yields were significantly increased under mulch obtained by killing rye one week before soybean planting during "dry/wet" and "wet/dry/dry" scenarios, not encountered during the field experiments.

3.3. Conclusions

The submodel WATBAL used by the CERES-Wheat and SOYGRO models adequately described the water balance in the sandy and medium loam soils for a no-mulch condition, but underestimated the soil moisture measured for medium and heavy mulch loads. The inclusion of equations in WATBAL describing the rainfall interception by the mulch layer, and the mulch effect on the surface albedo and the solar radiation available for soil water evaporation, resulted in

much better agreeement between observed and predicted soil moistures under mulch than the use of Steiner's model, as long as the minimum solar radiation transmittance was fixed at 10%. This simulated effect of the rye mulch on soil water content did not translate into significant simulated soybean yield increases when the observed weather data were input, corroborating the results obtained during field experiments, and indicating that the modelling approach used was realistic.

Rye dry matter amounts simulated for two spring killing dates were not significantly affected when the rainfall conditions in May were changed from "wet" to "dry", emphasizing the ability of the rye crop to withstand droughts. Delaying of rye killing significantly decreased the soil water content from the early to the late killing dates at the loam soil site during the "dry" condition. However, no further drying was observed after the early killing date at the sandy soil site, since on that date the soil water content was already approaching the lower limit of plant extractable water.

Simulated soybean seed yield for mulched treatments was always affected by the decrease in plant available water due to the rainfall interception by the mulch layer, and sometimes affected by rye water use before killing. Both the magnitude of interception and the reduction in soil water evaporation increased with the mulch amount present on the soil surface, so that a trade-off existed between those processes. Therefore, a mulch which minimizes rainfall interception per unit of mulch amount would be more efficient for soil water conservation.

In general, there was either no significant difference in simulated soybean yields between the rye killing date treatments, or the early rye killing outyielded the late killing date treatment. Also, the driest simulated rainfall scenario resulted in soybean crop failure for the late rye killing treatment at Delhi in 1990 and Woodstock during both study years. Therefore, based on the simulation results for the rye/soybean system presented, killing the rye cover crop approximately one week before soybean planting

seems to result in the best soybean yields under a variety of rainfall conditions, and on both medium and sandy textured soils.

REFERENCES

Aase, J. K., D.L. Tanaka. 1987. Soil water evaporation comparisons among tillage practices in the Northern Great Plains. Soil Sci. Soc. Am. J. 51: 436-440.

Acock, B., V.R. Reddy, F.D. Whisler, D.N. Baker, J.M. MacKinion, H.F. Hodges, and K.J. Boote. 1983. Response of vegetation to carbon dioxide, Series Number 002, the soybean crop simulator GLYCIM: Model Documentation 1982. USDA, ARS and Dept. of Agronomy, Mississippi State University.

Ashley, D. A., W.J. Ethridge. 1978. Irrigation effects on vegetative and reproductive development of three soybean cultivars. Agron. J. 70: 467-471.

Ashley, D. A. 1983. Soybean. In: Crop-water relations, I. D. Teare and M. M. Peet (eds.). John Wiley & Sons, Inc., New York, p. 389-422.

Blevins, R. L., M.S. Smith, G.W. Thomas. 1984. Changes in soil properties under no-tillage. In: No-tillage agriculture: Principles and practices. R.E. Phillips and S.H. Phillips (eds.). Van Nostrand Reinhold, Inc., New York. p. 190-230.

Blevins, R. L., D. Cook, S.H. Phillips, R.E. Phillips. 1971. Influence of no-tillage on soil moisture. Agron. J. 63: 593-596.

Blevins, R. L., M.S. Smith, G.W. Thomas, W.W. Frye. 1983. Influence of conservation tillage on soil properties. J. Soil Water Cons. 38: 301-305.

Bond, J. J., W.O. Willis. 1969. Soil water evaporation: surface residue rate and placement effect. Soil Sci. Soc. Am. J. 33: 445-448.

Bond, J. J., W.O. Willis. 1970. Soil water evaporation: First stage drying as influenced by surface residue and evaporation potential. Soil Sci. Soc. Am. Proc. 34: 924-928.

Brady, R. A., L.R. Stone, C.D. Nickell, W.L. Powers. 1974. Water conservation through proper timing of soybean irrigation. J. Soil Water Conserv. 29: 266-268.

Bristow, K.L. 1983. Simulation of heat and moisture through a surface residue-soil system. Ph.D. Thesis. Washington State University, Pullman, WA, 74pp.

Bushuk, W. 1976. Rye: production, chemistry, and technology. American Soc. Cereal Chemists, St. Paul.

Campbell, R. B., R.E. Sojka, D.L. Karlen. 1984. Conservation tillage for soybean in the U.S. southeastern coastal plain. Soil Tillage Res. 4: 531-541.

Chung, S.-O.; Horton, R. 1987. Soil heat and water flow with a partial surface mulch. Water Resour. Res., 23: 2175-2186.

Curry, R.B., R.M. Peart, J.W. Jones, K.J. Boote, L.H. Allen, Jr. 1990. Response of crop yield to predicted changes in climate and atmopsheric CO_2 using simulation. Trans. ASAE 33:1383-1390.

Deibert, E. J., R.A. Utter. 1989. Growth and NPK uptake by soybean cultivars in northern U.S.A. under reduced tillage systems. Can. J. Plant Sci. 69: 1101-1111.

Deibert, E. J. 1989. Soybean cultivar response to reduced tillage systems in northern dryland areas. Agron. J. 81: 672-676.

Doss, B. D., R.W. Pearson, H.T. Rogers. 1974. Effect of soil water stress at various growth stages on yield. Agron. J. 66: 297-299.

Eckert, D. J. 1988. Rye cover crops for no-tillage corn and soybean production. J. Prod. Agric. 1: 207-210.

Edwards, J. H., D.L. Thurlow, J.T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybean, and wheat. Agron. J. 80: 76-80.

Elmore, R. W. 1987. Soybean cultivar response to tillage systems. Agron. J. 79: 114-119.

Elmore, R. W. 1990. Soybean cultivar response to tillage systems and planting date. Agron. J. 82: 69-73.

Enz, J. W., L.J. Brun, J.K. Larsen. 1988. Evaporation and energy balance for bare and stubble covered soil. Agric. For. Meorol. 43: 59-70.

Fehr, W. R., J.S. Burris, D.F. Gilman. 1973. Soybean emergence under field conditions. Agron. J. 65: 740-742.

Fortin, M.-C., F.J. Pierce. 1990. Developmental and growth effects of crop residues in corn. Agron. J. 82: 710-715.

Gallaher, R. N. 1977. Soil moisture conservation and yield of crops no-till planted in rye. Soil Sci. Soc. Am. J. 41: 145-147.

Greb, B. W., D.E. Smika, A.L. Black. 1967. Effect of straw mulch rates on soil water storage during summer fallow in the great

plains. Soil Sci. Soc. Am. Proc. 31: 556-559.

Griffith, D. R., J.V. Mannering, H.M. Galloway, S.D. Parsons, C.B. Richey. 1973. Effect of eight tillage-planting systems on soil temperature, percent stand, plant growth, and yield of corn on five Indiana soils. Agron. J. 65: 321-326.

Griffith, D. R., J.V. Mannering, J.E. Box. 1986. Soil and moisture management with reduced tillage. In: No-tillage and surface tillage agriculture: The tillage revolution. M.A. Sprague and G.B. Triplett (eds.).John Wiley & Sons, Inc., New York. p. 19-57.

Groenevelt, P. H., P. van Straaten, V. Rasiah, J. Simpson. 1989. Modifications in evaporation parameters by rock mulches. Soil Technology 2: 279-285.

Gupta, S.C.; Radke, J.K.; Larson, W.E.; Shaffer, M.J. 1982. Predicting temperatures of bare- and residue-covered soils from daily maximum and minimum air temperatures. Soil Sci. Soc. Am. J., 46:372-376.

Gupta, S. C., W.E. Larson, D.R. Linden. 1983. Tillage and surface residue effects on soil upper boundary temperatures. Soil Sci. Soc. Am. J. 47: 1212-1218.

Hanks, R. J., S.A. Bowers, L.D. Bark. 1961. Influence of soil surface conditions on net radiation, soil temperature, and evaporation. Soil Sci. 91: 233-238.

Hood, C. P., R.W. McClendon, J.E. Hook. 1987. Computer analysis of soybean irrigation management strategies. Trans. Am. Soc. Agric. Eng. 30: 417-423.

Hovermale, C. H., H.M. Camper, M.W. Alexander. 1979. Effects of small grain stubble height and mulch on no-tillage soybean production. Agron. J. 71: 644-647.

Huck, M. G., K. Ishihara, C.M. Peterson, T. Ushijima. 1983. Soybean adaptation to water stress at selected stages of growth. Plant Physiol. 73: 422-427.

Hunt, L. A. 1991. Applications of crop modelling to quantify and reduce climatic risk. Workshop on "Changing climate in relation to sustainable agriculture", Agricultural Institute of Canada, Fredericton, N.B., July 27-31.

Hunt, L. A., S. Pararajasingham, D.T. Imamura, R.M. Ogoshi, J.W. Jones, and G.N. Hoogenboom. 1992. GENCALC - A computer program to facilitate the use of crop models in the analysis of field experiments. (submitted).

International Benchmark Sites Network for Agrotechnology Project. 1986. Technical Report 5. Decision Support System for Agrotechnology Transfer (DSSAT). Documentation for IBSNAT crop model input and output files, Version 1.0. Dept. Agronomy and Soil Sci., College of Trop. Agr. and Human Resources, University of Hawaii, Honolulu, Hawaii 96822.

Johnson, M. D., B. Lowery. 1985. Effect of three conservation tillage practices on soil temperature and thermal properties. Soil Sci. Soc. Am. J. 49: 1547-1552.

Jones, J. N., Jr, J.E. Moody, J.H. Lillard. 1969. Effects of tillage, no tillage, and mulch on soil water and plant growth. Agron. J. 61: 719-721.

Jones, J. W., K.J. Boote, G. Hoogenboom, S.S. Jagtap, G.G. Wilkerson. 1989. SOYGRO V5.42: Soybean crop growth simulation model. User's guide. 75p.

Jones, J. W., K.J. Boote, S.S. Jagtap, and J.W. Mishoe. 1991. Soybean development. In: Modeling plant and soil systems. J. Hanks and J.T. Ritchie (eds.). ASA, CSSA, SSSA, Madison, WI. Agronomy Series 31. p. 71-90.

Joyce, L.A. and R.N. Kickert. 1987. Applied plant growth models for grazing lands, forest and crops. In: Plant growth modeling for resource management. K. Wisiol and J.D. Hesketh (eds.), CRC Press, Boca Raton, vol. I, p.17-56.

Kadhem, F. A., J.E. Specht, J.H. Williams. 1985a. Soybean irrigation serially timed during stages R1 to R6. I. Agronomic responses. Agron. J. 77: 291-298.

Kadhem, F. A., J.E. Specht, J.H. Williams. 1985b. Soybean irrigation serially timed during stages R1 to R6. II. Yield component responses. Agron. J. 77: 299-304.

Korte, L. L., J.H. Williams, J.E. Specht, R.C. Sorensen. 1983a. Irrigation of soybean genotypes during reproductive ontogeny. I. Agronomic responses. Crop Sci. 23: 521-528.

Korte, L. L., J.E. Specht, J.H. Williams, R.C. Sorensen. 1983b. Irrigation of soybeans genotypes during reproductive ontogeny. II. Yield component responses. Crop Sci. 23: 528-533.

Laflen, J. M., M. Amemiya, E.A. Hintz. 1981. Measuring crop residue cover. J. Soil Water Cons. 36: 341-343.

Lindemann, W. C., G.E. Ham. 1979. Soybean plant growth, nodulation, and nitrogen fixation as affected by root temperature. Soil Sci. Soc. Am. J. 43: 1134-1137.

Lindemann, W. C., G.W. Randall, G.E. Ham. 1982. Tillage effects on soybean nodulation, N2(C2H4) fixation, and seed yield. Agron. J. 74: 1067-1070.

Meyer, G. E., R.B. Curry, J.G. Streeter, and H.J. Mederski. 1979. SOYMOD/OARDC a dynamic simulator of soybean growth, development and seed yield: I. Theory, structure, and validation. OARDC Res. Bull. 1113, Wooster, Ohio.

Moody, J. E., J.N. Jones, Jr., J.H. Lillard. 1963. Influence of straw mulch on soil moisture, soil temperature and growth of corn. Soil Sci. Soc. Am. Proc. 27: 700-703.

Moschler, W. W., G.M. Shear, D.L. Hallock, R.D. Sears, G.D. Jones. 1967. Winter cover crops for sod-planted corn: Their selection and management. Agron. J. 59: 547-551.

Muendel, H.-H. 1986. Emergence and vigor of soybean in relation to initial seed moisture and soil temperature. Agron. J. 78: 765-769.

Munawar, A. R. L. Blevins, W.W. Frye, M.R. Saul. 1990. Tillage and cover crop management for soil water conservation. Agron. J. 82: 773-777.

NeSmith, D. S., W.L. Hargrove, D.E. Radcliffe, E.W. Tollner, H.H. Arioglu. 1987. Tillage and residue management effects on properties of an ultisol and double-cropped soybean production. Agron. J. 79: 570-576.

Obendorf, R. L., P.R. Hobbs. 1970. Effect of seed moisture on temperature sensitivity during imbibition of soybean. Crop Sci. 10: 563-566.

Oke, T.R., 1987. Boundary layer climates. Methuen, Inc., New York, 2nd. edition. 435 p.

Parsch, L.D., M.J. Cochran, K.L. Trice, and H. Don Scott. 1991. Biophysical simulation of wheat and soybean to assess the impact of timeliness on double-cropping economics. In: Modeling plant and soil systems. J.H. Hanks and J.T. Ritchie (eds.). ASA, CSSA, SSSA, Madison, WI. Agronomy Series 31. p. 511-534.

Phillips, R. E. 1986. Effects of climate on performance of no-tillage. In: No-tillage agriculture: Principles and practices. R.E. Phillips and S.H. Phillips (eds.). Van Nostrand Reinhold, Inc., New York. p. 11-41.

Phillips, R. E., R.L. Blevins, G.W. Thomas. 1980. No-tillage agriculture. Science 208: 1108-1113.

Priestley, C. H. B., and R.J. Taylor. 1972. On the assessment of surface heat and evaporation using large-scale parameters. Monthly Weather Rev. 100:81-92.

Raimbault, B. A., T.J. Vyn, M. Tollenaar. 1990. Corn response to rye cover crop management and spring tillage systems. Agron. J. 82: 1088-1093.

Ritchie, J. T. 1972. Model for predicting evaporation from a row crop with incomplete cover. Water Resour. Res. 8:1204-1213.

Ritchie, J.T. 1981. Soil water availability. Plant and Soil 58:327-338.

Ritchie, J. T. 1985. A user-oriented model of the soil water balance in wheat. In: Wheat growth and modelling. W. Day and R.K. Atkin (eds.). Plenum Publishing Corporation, NATO-ASI Series. 293-305.

Ross, P.J.; Williams, J.; McCown, R.L. 1985. Soil temperature and the energy balance of vegetative mulch in the semi-arid tropics. II. Dynamic analysis of the total energy balance. Aust. J. Soil Res., 23:515-532.

Rudd, W. G., W.G. Ruesink, C.D. Newsom, D.C. Herzog, R.L. Jensen, N.F. Marsolan. 1980. The systems approach to research and decision making for soybean pest control. C.B. Huffaker (ed.). New technology of pest control. John Wiley & Sons, Inc., New York. 99-122.

Runge, E. C. A., R.T. Odell. 1960. The relation between precipitation, temperature, and the yield of soybeans on the Agronomy South Farm, Urbana, Illinois. Agron. J. 52: 245-247.

Shaffer, M.J., S.C. Gupta, D.R. Linden, J.A.E Molina, C.E. Clapp, and W.E. Larson. 1983. Simulation of nitrogen, tillage, and residue management effects on soil fertility. In: Analysis of ecological systems: state-of-the-art in ecological modeling. W.K. Lauenroth, G.V. Skogerboe, and M. Flug (ed.). Elsevier, New York. p. 525-544.

Sinclair, T. R., R.C. Muchow, J.M. Bennett, L.C. Hammond. 1987. Relative sensitivity of nitrogen and biomass accumulation to drought in field-grown soybean. Agron. J. 79: 986-991.

Sinclair, T. R., P.R. Weisz. 1985. Response to soil temperature of dinitrogen fixation (acetylene reduction) rates by field-grown soybeans. Agron. J. 77: 685-688.

Sionit, N. P. J. Kramer. 1977. Effect of water stress during different stages of growth of soybean. Agron. J. 69: 274-278.

Steiner, J. L. 1989. Tillage and surface residue effects on evaporation from soils. Soil Sci. Soc. Am. J. 53: 911-916.

Stott, D. E., H.F. Stroo, L.F. Elliott, R.I. Papendick, P.W. Unger. 1990. Wheat residue loss from fields under no-till management. Soil Sci. Soc. Am. J. 54: 92-98.

Swaney, D. P., J.W. Mishoe, J.W. Jones, W.G. Boggess. 1983. Using crop models for management: Impact of weather characteristics on irrigation decisions in soybeans. Trans. Am. Soc. Agric. Eng. 26: 1808-1814.

Tanner, C. B., Y. Shen, I.A. Saeed. 1987. Radiation, sensible heat, and vapor transfer in flail-chopped corn residue on the soil surface. Final report. University of Wisconsin State, Madison, Wisconsin. 162 p.

Thompson, L. M. 1970. Weather and technology in the production of soybeans in the Central United States. Agron. J. 62: 232-236.

Tollner, E. W., W.L. Hargrove, G.W. Langdale. 1984. Influence of conventional and no-till practices on soil physical properties in the southern Piedmont. J. Soil Water Cons. 73-76.

Triplett, G. B. 1986. Crop management practices for surface-tillage systems. In: No-Tillage and surface-tillage agriculture: The tillage revolution. M.A. Sprague and G.B. Triplett (eds.). John Wiley & Sons, Inc., New York. p. 149-182.

Tyler, D. D., J.R. Overton. 1982. No-tillage advantages for soybean seed quality during drought stress. Agron. J. 74: 344-347.

Unger, P. W. 1978. Straw-mulch rate effect on soil water storage and sorghum yield. Soil Sci. Soc. Am. J. 42: 486-491.

Unger, P. W. 1988. Residue management effects on soil temperature. Soil Sci. Soc. Am. J. 52: 1777-1782.

Van Doren, D. M., Jr.,R.R. Allmaras. Effect of residue management practices on the soil physical environment, microclimate, and plant growth. In: Crop residue management systems. W.R. Oschwald (ed.). Spec. Publ. 31. American Society of Agronomy, Madison, Wisconsin. p. 49-83.

Wagger, M. G. 1989. Time of desiccation effects on plant composition and subsequent nitrogen release from several winter annual cover crops. Agron. J. 81: 236-241.

Wagner Riddle, C. 1992. The eefect of rye mulch on soybean yield: a field and modelling study. PhD. Thesis, University of

Guelph, 248 p.

Wann, M. C. D. Raper, Jr. 1979. A dynamic model for plant growth: Adaptation for vegetative growth of soybeans. Crop Sci. 19: 461-467.

Webber III, C. L., M.R. Gebhardt, H.D. Kerr. 1987. Effect of tillage on soybean growth and seed production. Agron. J. 79: 952-956.

Weston, L. A. 1990. Cover crop and herbicide influence on row crop seedling establishment in no-tillage culture. Weed Sci. 38: 166-171.

Whisler, F.D. et al. 1986. Crop simulation models in agronomic systems. Adv. Agron. 40:141-208.

Wilhelm, W. W., J.W. Doran, J.F. Power. 1986. Corn and soybean yield response to crop residue management under no-tillage production systems. Agron. J. 78: 184-189.

Wilkerson, G. G., J.W. Jones, K.J. Boote, K.T. Ingram, J.W. Mishoe. 1983. Modeling soybean growth for management. Trans. Am. Soc. Agric. Eng. 26: 63-73.

Zhai, R. R. G. Kachanoski, R.P. Voroney. 1990. Tillage effects on the spatial and temporal variations of soil water. Soil Sci. Soc. Am. J. 54: 186-192.

APPENDIX A

Section 2

Daily weather

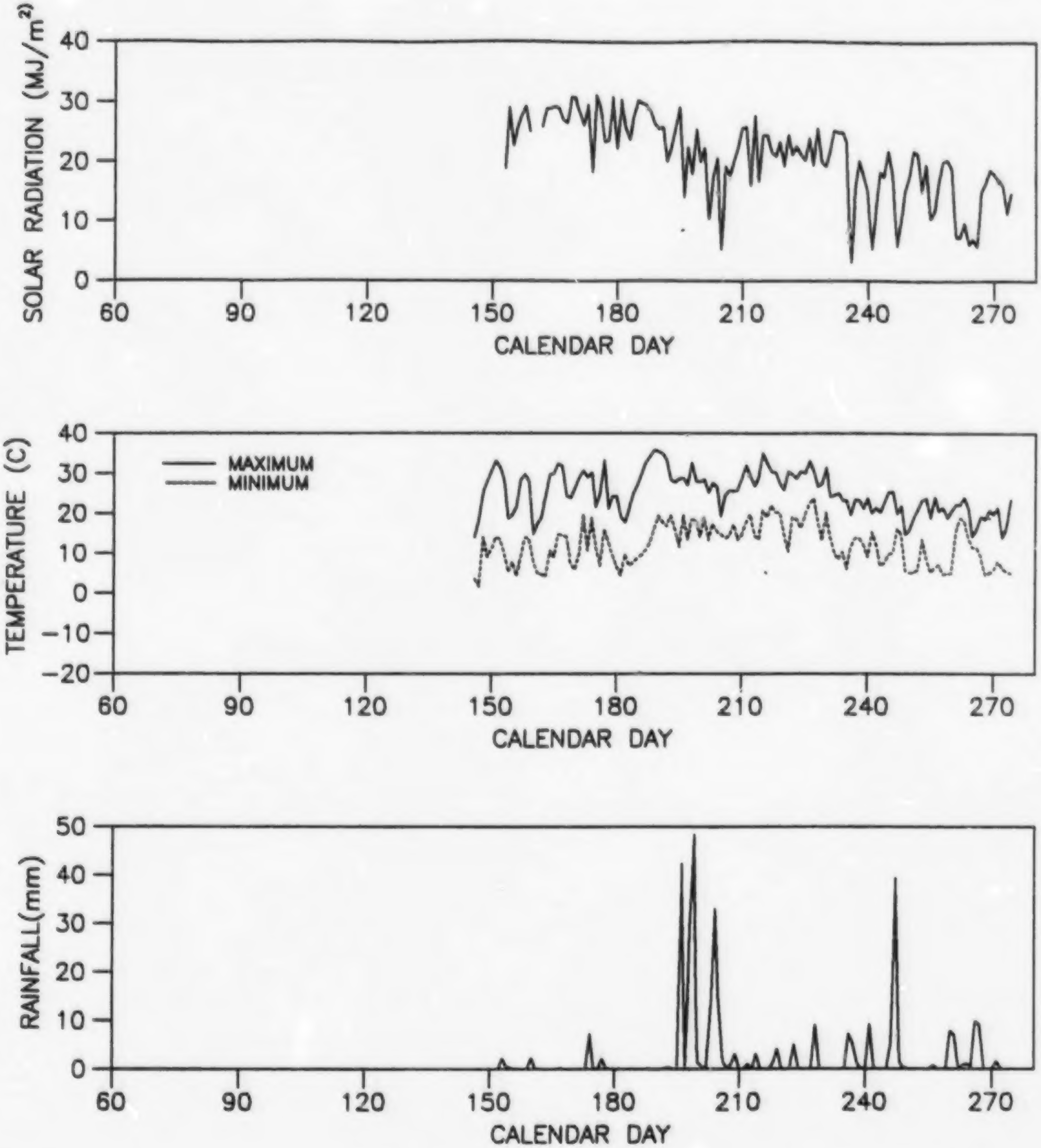

Figure A.1 - Daily weather variables measured at Delhi after soybean planting in 1988.

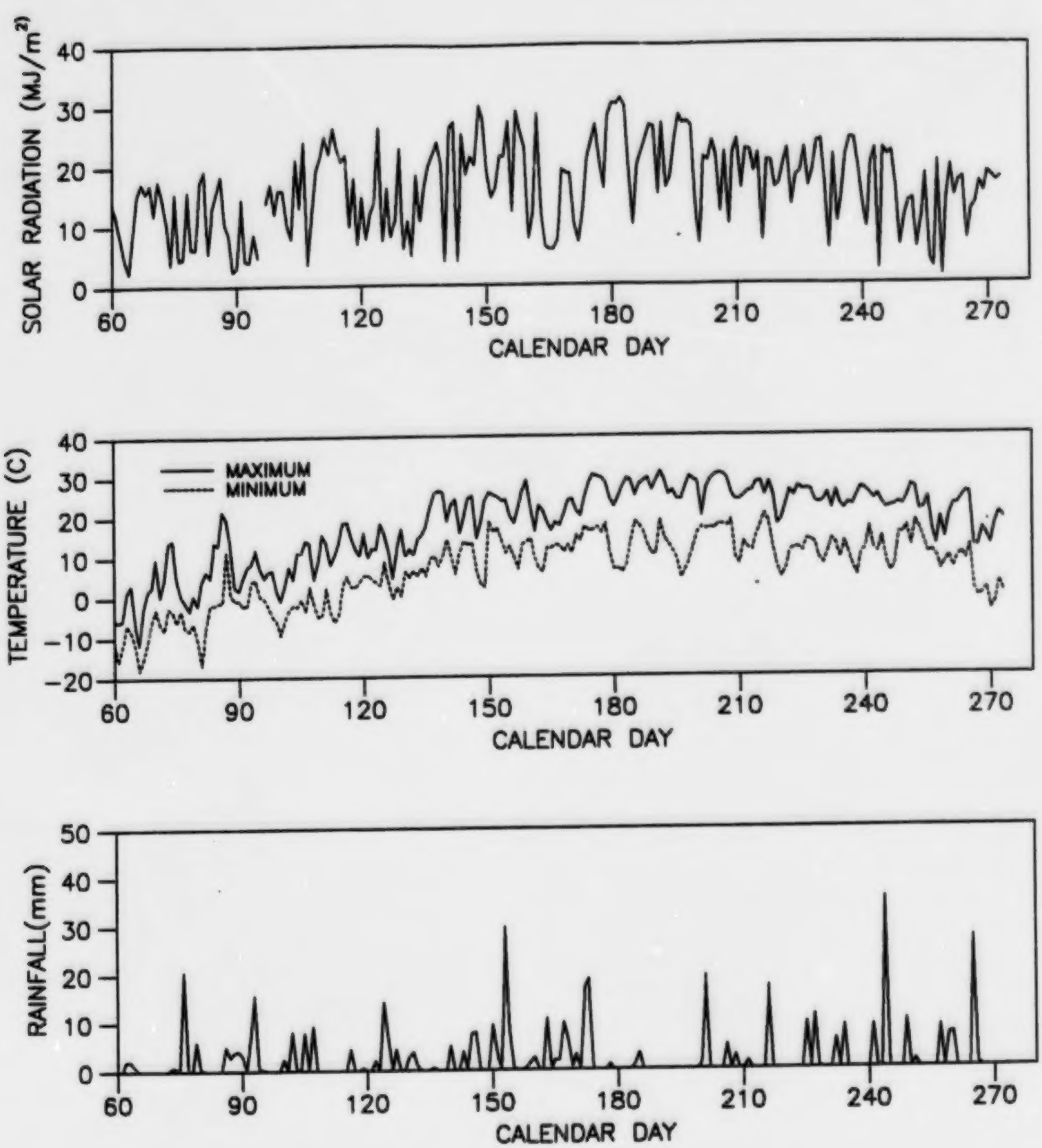

Figure A.2 - Daily weather variables measured at Delhi from March 1 to September 30, 1989.

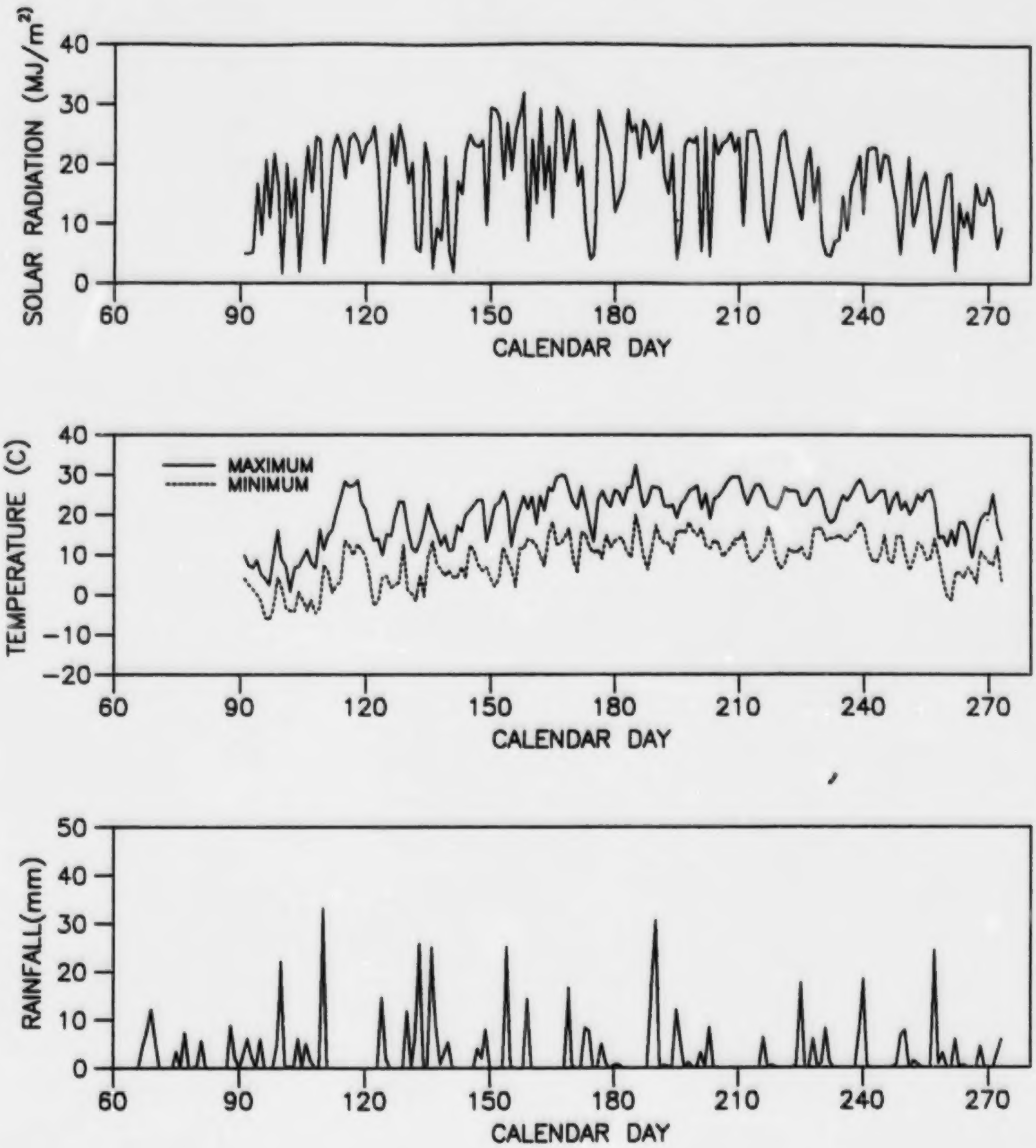

Figure A.3 - Daily weather variables measured at Delhi from March 1 to September 30, 1990.

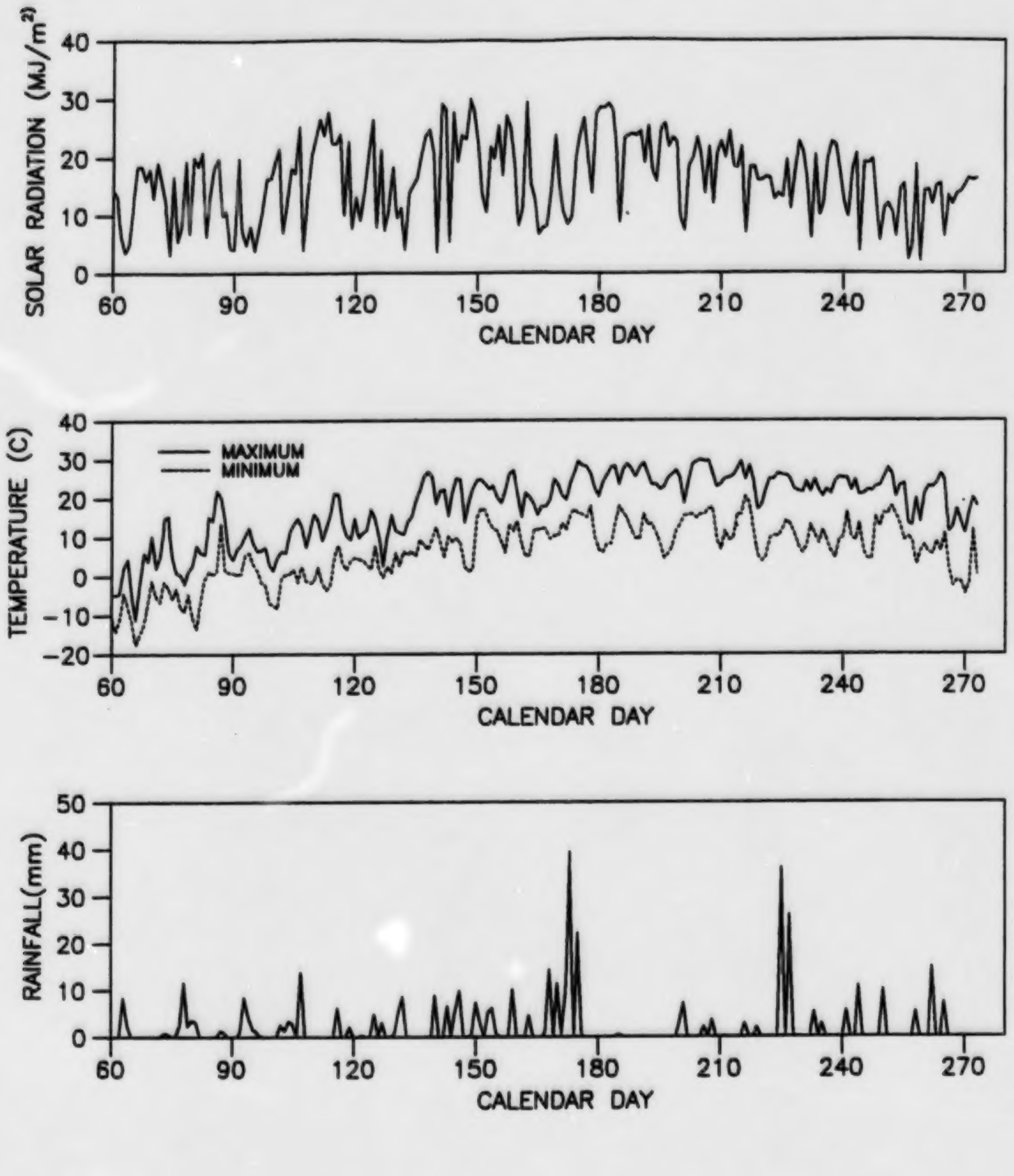

Figure A.4 - Daily weather variables measured at Woodstock from March 1 to September 30, 1989.

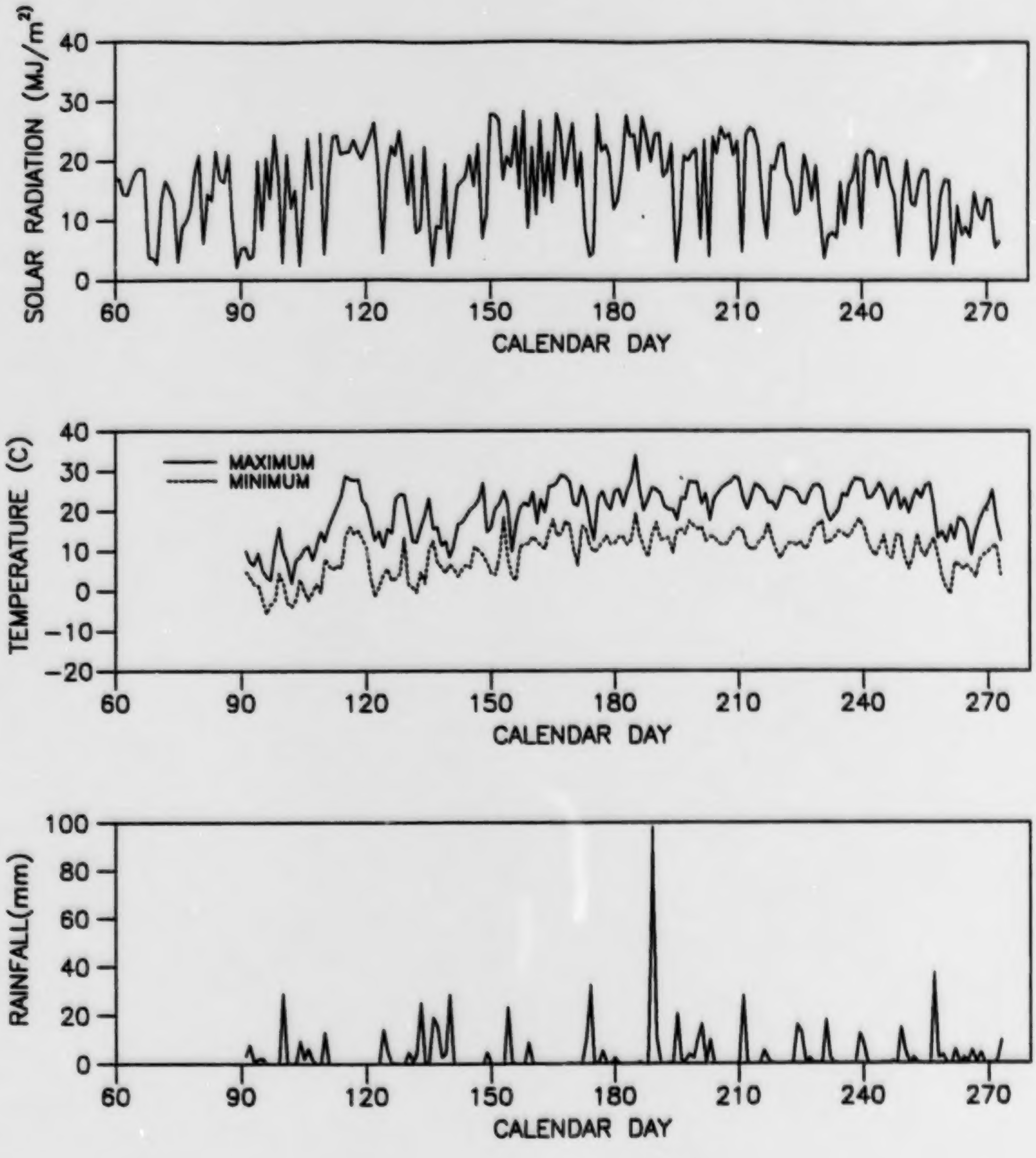

Figure A.5 - Daily weather variables measured at Woodstock from March 1 to September 30, 1990.

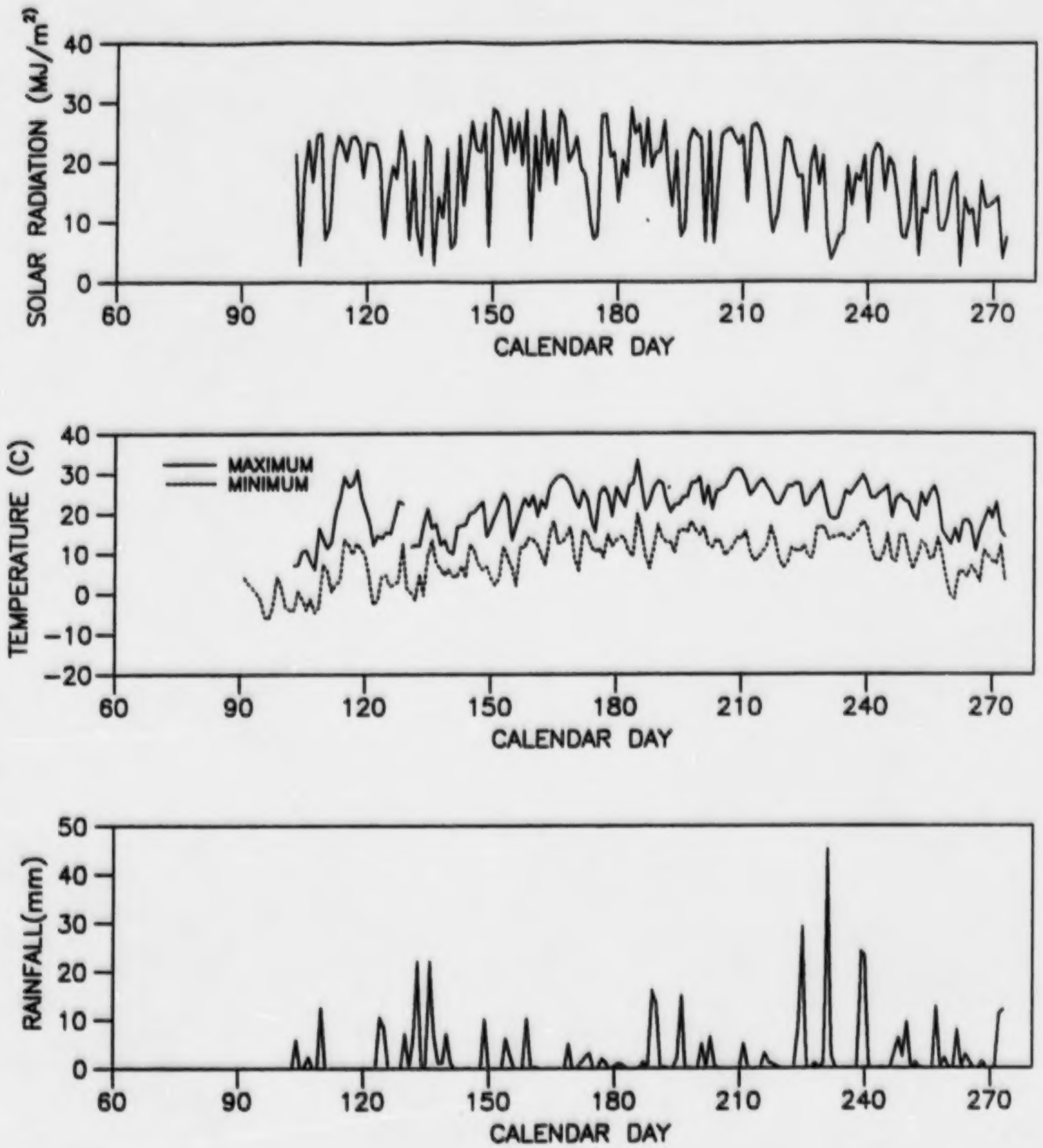

Figure A.6 - Daily weather variables measured at Canfield from April 13 to September 30, 1990.

APPENDIX B

Section 2

CERES-Wheat input files
SOYGRO input files

Table B.1 - Soil profile properties (File 2) for Woodstock and Delhi. [For detailed explanation of variables see IBSNAT (1986)].

10 IBSNAT DEEP SAND Delhi

.15 4.00 .50 70.00 6.9 13.9 1.0 1.32E-03 112.0 6.67 .04 1.00

1	2	3	4	5	6	7	8	9	10	11
10.	.068	.206	.450	.206	1.000	1.66	.29	2.5	3.3	6.5
20.	.066	.150	.410	.150	0.819	1.66	.28	2.4	3.2	6.5
15.	.047	.150	.384	.150	.607	1.66	.24	2.2	3.0	6.5
15.	.047	.150	.384	.150	.407	1.66	.19	2.0	2.7	6.5
15.	.047	.100	.267	.100	.407	1.66	.19	2.0	2.7	6.5
30.	.047	.100	.267	.100	.247	1.66	.12	1.8	2.3	6.5
30.	.047	.100	.267	.100	.247	1.66	.06	1.5	1.9	6.5
30.	.047	.100	.267	.100	.247	1.66	.06	1.5	1.9	6.5
30.	.047	.100	.267	.100	.135	1.66	.06	1.5	1.9	6.5

05 MEDIUM SILT LOAM Woodstock

.12 6.00 .50 79.00 6.9 13.9 1.0 1.32E-03 93.1 6.67 .04 1.00

1	2	3	4	5	6	7	8	9	10	11
10.	.170	.330	.490	.360	1.000	1.37	1.16	2.5	3.3	6.5
20.	.170	.330	.490	.362	.819	1.37	1.10	2.4	3.2	6.5
15.	.170	.330	.490	.382	.607	1.37	.97	2.2	3.0	6.5
15.	.170	.330	.490	.382	.407	1.38	.75	2.0	2.7	6.5
30.	.170	.330	.490	.261	.407	1.38	.75	2.0	2.7	6.5

Variable description:

- line 1 - soil number and type

- line 2 - soil albedo, upper limit of stage 1 evaporation (mm), soil water drainage constant, SCS curve number, annual average temperature (C), annual amplitude in mean monthly temperature (C), reduction factor for humus mineralization, coefficient in root uptake equation (3), maximum daily root uptake (cm^3/cm root-day), photosynthesis reduction factor due to soil fertility

- line 3 - column number

- column 1 - thickness of soil layer (cm)
  2 - lower limit of plant-extractable soil water (m^3/m^3)
  3 - drained upper limit soil water content (m^3/m^3)
  4 - saturated soil water content (m^3/m^3)
  5 - default soil water content (m^3/m^3)
  6 - root growth weighting factor
  7 - moist soil bulk density (g/cm^3)
  8 - organic carbon (%)
  9 - default soil ammonium (mg N/kg soil)
  10 - default soil nitrate (mg N/kg soil
  11 - default pH

Table B.2 - Genetic coefficients for CERES-Wheat (File 9). For detailed explanation of variables see IBSNAT (1986).

9800FREDERICK	6.0	2.7	2.0	3.8	1.6	1.9

Variable description:

- sensitivity coefficient to vernalization, sensitivity coefficient to daylength, thermal time between beginning of grain filling and maturity (C-day), specific constant related to rate of vegetative expansion during stage 1, constant related to the number of grains produced, constant for determining grain fill rate (mg/day)

Table B.3 - General genetic coefficients for SOYGRO (File 9). For explanation of variables see Jones et al. (1989).

0038 MG-00 00 0.00 5.88 6.10 43.16 20.30 1.50 9.50 13.00 9.50 6.0 2.10 3.50 17.2 36.0 1.00

Variable description:

- variety number and name, maturity group, duration of juvenile phase, duration of floral induction phase, duration from flowering to first pod appearance, duration from flowering to physiological maturity, duration from flowering to last leaf expansion, VARTH*, VARNO, PODVAR, SHVAR, SDVAR, SDPDVR, number of trifoliates produced per day, area of normal leaf, specific leaf area for new leaves, PGLF

* see text for explanation of these variables

Table B.4 - Rye treatment management data (File 8), for locations and years studied. For detailed explanation of variables see IBSNAT (1986).

Delhi 1988/89

UCDH8801		01 RYE								10 9800		
270	270	288.00	0.180	4.00	1	0	0.75	0.50	40.0	95.00	0	

Delhi 1989/90

UCDH8901		01 RYE								10 9800	
263	263	221.00	0.180	4.00	1	0	0.75	0.50	40.0	95.00	0

Woodstock 1988/89

UCWK8801		01 RYE								05 9800	
288	288	267.00	0.180	4.00	1	0	0.75	0.50	40.0	95.00	0

Woodstock 1989/90

UCWK8901		01 RYE								05 9800	
265	265	346.20	0.180	4.00	1	0	0.75	0.50	40.0	95.00	0

Variable description:

- line 1 - experiment and treatment code, soil number, variety number
- line 2 - calendar day for start of simulation, planting day, plant population (plants/m^2), row spacing, seeding depth, switch for irrigation, switch for nitrogen subroutine, irrigation efficiency, irrigation depth, available water triggering irrigation, phyllochron interval (C-day), switch for phenology

Table B.5 - Soybean treatment management data (File 8), for locations and years studied. For detailed explanation of variables see IBSNAT (1986).

Delhi 1989

```
UCDH8901    01  EARLY   KILL                                      1534.0      10     05
 144  144    34.40     0.400     0.04    1  00     0.75     0.50      40.0     95.00     0
UCDH8901    02  LATE    KILL                                      2093.0      10     05
 144  144    31.70     0.400     0.04    1  00     0.75     0.50      40.0     95.00     0
UCDH8901    03  PLOWED                                               0.0      10     05
 144  144    32.70     0.400     0.04    1  00     0.75     0.50      40.0     95.00     0
```

Delhi 1990

```
UCDH9001    01  EARLY   KILL                                      2250.0      10     05
 143  143    30.80     0.400     0.04    1  00     0.75     0.50      40.0     95.00     0
UCDH9001    02  LATE    KILL                                      3478.0      10     05
 143  143    20.80     0.400     0.04    1  00     0.75     0.50      40.0     95.00     0
UCDH9001    03  PLOWED                                               0.0      10     05
 143  143    33.00     0.400     0.04    1  00     0.75     0.50      40.0     95.00     0
```

Woodstock 1989

```
UCWK8901    01  EARLY   KILL                                      2311.0      05     07
 149  149    34.80     0.400     0.04    1  00     0.75     0.50      40.0     95.00     0
UCWK8901    02  LATE    KILL                                      2915.0      05     07
 149  149    32.60     0.400     0.04    1  00     0.75     0.50      40.0     95.00     0
UCWK8901    03  PLOWED                                               0.0      05     07
 149  149    29.60     0.400     0.04    1  00     0.75     0.50      40.0     95.00     0
```

Woodstock 1990

```
UCWK9001    01  EARLY   KILL                                      3459.0      05     07
 152  152    44.90     0.400     0.04    1  00     0.75     0.50      40.0     00.00     0
UCWK9001    02  LATE    KILL                                      4776.0      05     07
 152  152    41.60     0.400     0.04    1  00     0.75     0.50      40.0     00.00     0
UCWK9001    03  BARE                                                 0.0      05     07
 152  152    39.50     0.400     0.04    1  00     0.75     0.50      40.0     00.00     0
```

Variable description:

- line 1 - experiment and treatment code, soil number, variety number

- line 2 - calendar day for start of simulation, planting day, plant population (plants/m^2), row spacing, seeding depth, switch for irrigation, switch for nitrogen subroutine, irrigation efficiency, irrigation depth, available water triggering irrigation, phyllochron interval (C-day), switch for phenology

Table B.6 - Soil profile conditions at start of rye simulation (File 5), for locations and years studied. For detailed explanation of variables see IBSNAT (1986).

Delhi 1988/89

01 UCDH8801

10.	0.131	1.0	6.5	5.4
20.	0.131	1.0	6.5	5.4
15.	0.127	1.0	6.5	5.4
15.	0.127	1.0	6.5	5.4
15.	0.127	1.0	6.5	5.4
30.	0.127	1.0	6.5	5.4
30.	0.127	1.0	6.5	5.4
30.	0.127	1.0	6.5	5.4
30.	0.127	1.0	6.5	5.4
-1.	-1.000	0.0	.0	.0

Delhi 1989/90

01 UCDH8901

10.	0.119	1.0	6.5	5.4
20.	0.208	1.0	6.5	5.4
15.	0.129	1.0	6.5	5.4
15.	0.129	1.0	6.5	5.4
15.	0.129	1.0	6.5	5.4
30.	0.129	1.0	6.5	5.4
30.	0.129	1.0	6.5	5.4
30.	0.129	1.0	6.5	5.4
30.	0.129	1.0	6.5	5.4
-1.	-1.000	0.0	.0	.0

Woodstock 1988/89

01 UCWK8801

10.	0.320	2.6	19.0	7.2
20.	0.320	2.6	19.0	7.2
15.	0.245	2.6	19.0	7.2
15.	0.245	2.6	19.0	7.2
30.	0.330	2.6	19.0	7.2
-1.	-1.000	0.0	.0	.0

Woodstock 1989/90

01 UCWK8901

10.	0.259	2.6	19.0	7.2
20.	0.259	2.6	19.0	7.2
15.	0.200	2.6	19.0	7.2
15.	0.200	2.6	19.0	7.2
30.	0.330	2.6	19.0	7.2
-1.	-1.000	0.0	.0	.0

Variable description:

- line 1 - treatment number, experiment code
- line 2 to nth - depth of layer, soil water content (cm^3/cm^3), soil ammonium (mg N/kg soil), soil nitrate (mg N/kg soil), pH

Table B.7 - Soil profile conditions at start of soybean simulation (File 5), for locations and years studied. For detailed explanation of variables see IBSNAT (1986).

Delhi 1989

01 UCDH8901

10.	0.146	3.2	11.4	6.1
20.	0.144	0.0	.0	.0
15.	0.095	0.0	.0	.0
15.	0.095	0.0	.0	.0
15.	0.095	0.0	.0	.0
30.	0.100	0.0	.0	.0
30.	0.100	0.0	.0	.0
30.	0.100	0.0	.0	.0
30.	0.100	0.0	.0	.0
-1.	-1.000	0.0	.0	.0

02 UCDH8901

10.	0.107	3.2	11.4	6.1
20.	0.120	0.0	00.0	.0
15.	0.080	0.0	00.0	.0
15.	0.080	0.0	00.0	.0
15.	0.080	0.0	00.0	.0
30.	0.100	0.0	00.0	.0
30.	0.100	0.0	00.0	.0
30.	0.100	0.0	00.0	.0
30.	0.100	0.0	0.0	.0
-1.	1.	.0	.0	.0

03 UCDH8901

10.	0.150	3.2	11.4	6.1
20.	0.152	0.0	00.0	.0
15.	0.117	0.0	00.0	.0
15.	0.117	0.0	00.0	.0
15.	0.117	0.0	00.0	.0
30.	0.100	0.0	00.0	.0
30.	0.100	0.0	00.0	.0
30.	0.100	0.0	0.0	.0
30.	0.100	0.0	0.0	.0
-1.	-1.000	0.0	.0	.0

Delhi 1990

01 UCDH9001

10.	0.158	0.0	0.0	6.5
20.	0.189	0.0	.0	.0
15.	0.151	0.0	.0	.0
15.	0.151	0.0	.0	.0
15.	0.151	0.0	.0	.0
30.	0.151	0.0	.0	.0
30.	0.151	0.0	.0	.0
30.	0.151	0.0	.0	.0
30.	0.151	0.0	.0	.0
-1.	-1.000	0.0	.0	.0

02 UCDH9001

cont...

	10.	0.170	0.0	.0	6.5
	20.	0.182	0.0	00.0	.0
	15.	0.153	0.0	00.0	.0
	15.	0.153	0.0	00.0	.0
	15.	0.153	0.0	00.0	.0
	30.	0.153	0.0	00.0	.0
	30.	0.153	0.0	00.0	.0
	30.	0.153	0.0	0.0	.0
	30.	0.153	0.0	0.0	.0
	-1.	-1.	.0	.0	.0
03	UCDH901				
	10.	0.167	0.0	.0	6.5
	20.	0.181	0.0	00.0	.0
	15.	0.146	0.0	00.0	.0
	15.	0.146	0.0	00.0	.0
	15.	0.146	0.0	00.0	.0
	30.	0.146	0.0	00.0	.0
	30.	0.146	0.0	00.0	.0
	30.	0.146	0.0	0.0	.0
	30.	0.146	0.0	0.0	.0
	-1.	-1.000	0.0	.0	.0

Woodstock 1989

01	UCWK8901				
	10.	0.330	3.7	12.5	.0
	20.	0.330	0.0	.0	.0
	15.	0.255	0.0	.0	.0
	15.	0.255	0.0	.0	.0
	30.	0.330	0.0	.0	.0
	-1.	-1.000	0.0	.0	.0
02	UCWK8901				
	10.	0.255	3.7	12.5	.0
	20.	0.255	0.0	.0	.0
	15.	0.255	0.0	.0	.0
	15.	0.255	0.0	.0	.0
	30.	0.330	0.0	.0	.0
	-1.	1.	.0	.0	.0
03	UCWK8901				
	10.	0.330	3.7	12.5	.0
	20.	0.330	0.0	.0	.0
	15.	0.330	0.0	.0	.0
	15.	0.330	0.0	.0	.0
	30.	0.330	0.0	.0	.0
	-1.	-1.000	0.0	.0	.0

Woodstock 1990

01	UCWK9001				
	10.	0.413	.0	.0	7.2
	20.	0.358	.0	.0	.0
	15.	0.253	.0	.0	.0
	15.	0.253	.0	.0	.0

cont...

	30.	0.253	.0	.0	.0
	-1.	-1.000	0.0	.0	.0
02	UCWK9001				
	10.	0.428	.0	.0	7.2
	20.	0.353	0.0	00.0	.0
	15.	0.245	0.0	00.0	.0
	15.	0.245	0.0	00.0	.0
	30.	0.245	0.0	00.0	.0
	-1.	1.	.0	.0	.0
03	UCWK9001				
	10.	0.280	0.0	.0	7.2
	20.	0.363	0.0	00.0	.0
	15.	0.295	0.0	00.0	.0
	15.	0.295	0.0	00.0	.0
	30.	0.335	0.0	00.0	.0
	-1.	-1.000	0.0	.0	.0

Variable description:

- line 1 - treatment number, experiment code
- line 2 to nth - depth of layer, soil water content (cm^3/cm^3), soil ammonium (mg N/kg soil), soil nitrate (mg N/kg soil), pH

Table B.8 - Measured soybean crop summary data (File A), for locations and years studied. For detailed explanation of variables see IBSNAT (1986) and Jones et al. (1989).

Delhi 1989

UCDH8901	1	2061.	.1585	1299.	2.10	2.59	3455.	667.	189	256
208	208	2788.								
UCDH8901	2	2254.	.1561	1481.	2.30	2.59	3718.	706.	189	256
208	208	3012.0								
UCDH8901	3	2403.	.1585	1555.	2.00	3.04	4013.	711.	189	255
207	207	3302.								

Delhi 1990

UCDH9001	1	4548.	.1670	2736.	2.28	5.20	7351.	1374.	192	258
212	212	5977.								
UCDH9001	2	3731.	.1699	2197.	2.30	4.05	5898.	969.	192	258
211	211	4929.								
UCDH9001	3	4472.	.1771	2527.	2.22	4.47	7267.	1426.	192	256
210	210	5841.								

Woodstock 1989

UCWK8901	1	3162.5	.1493	2113.	2.30	3.68	5073.	904.	195	252
205	205	4169.								
UCWK8901	2	3305.6	.1502	2187.	2.30	3.11	5214.	815.	196	253
205	205	4399.								
UCWK8901	3	3708.1	.1549	2374.	2.20	3.22	5974.	1066.	194	251
205	205	4908.								

Woodstock 1990

UCWK9001	1	4401.3	.1645	2669.	2.02	3.67	6982.	1109.	198	244
212	212	5873.								
UCWK9001	2	5131.4	.1596	3210.	2.10	4.06	8007.	1185.	198	244
212	212	6822.								
UCWK9001	3	4772.6	.1600	2979.	2.11	4.30	7860.	1498.	197	245
213	213	6362.								

Variable description:

- experiment code, treatment number, field-measured grain yield (kg/ha), field-measured seed dry weight (g/seed), field-measured seed number (seed/m^2), field-measured seed per pod, leaf area index at R4 stage, field-measured aboveground dry biomass at maturity (kg/ha), field-measured stem dry weight at maturity (kg/ha), field-measured flowering date (R1 stage), field-measured physiological maturity (R7 stage), field-measured first pod and full pod date, field-measured pod yield (kg/ha).

APPENDIX C

Section 3

CERES-Wheat simulation results

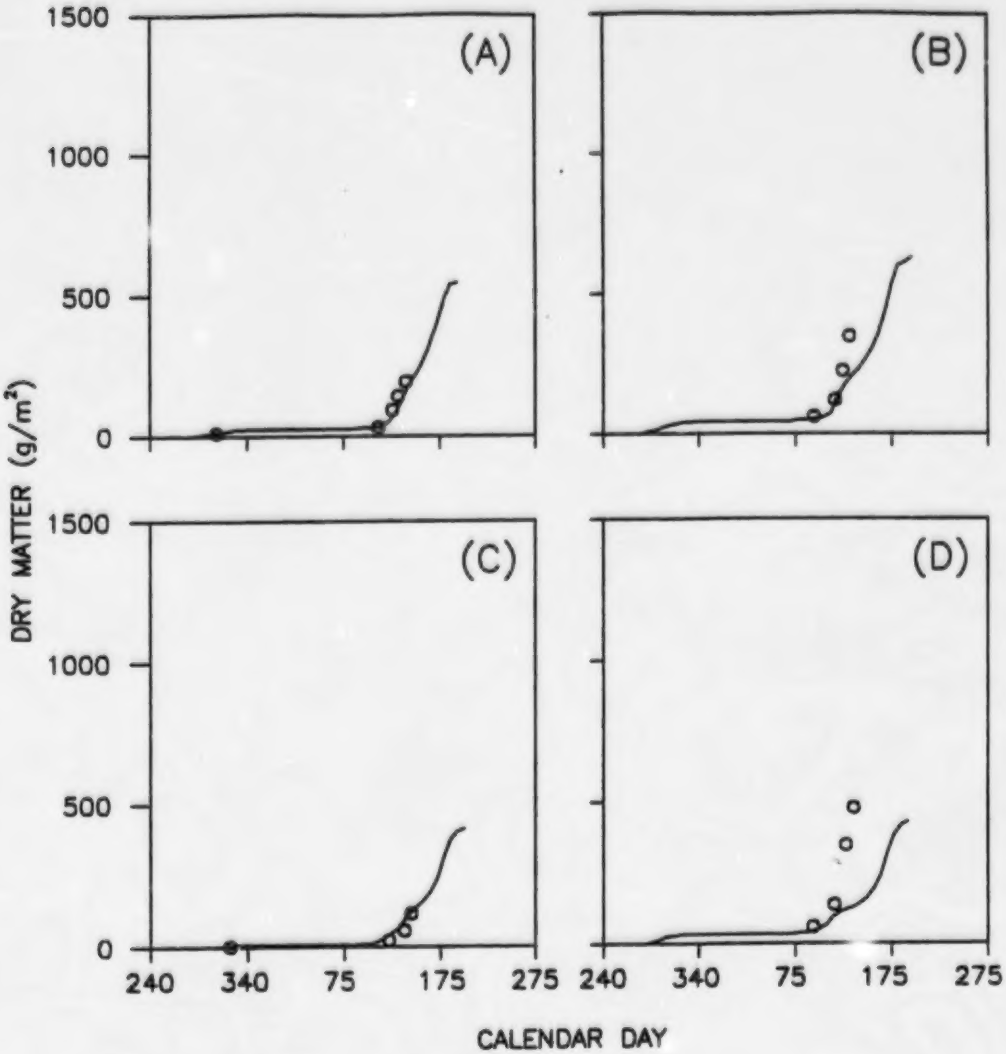

Figure C.1 - Rye dry matter accumulation simulated using the CERES-Wheat model with nitrogen subroutine activated (solid line) versus observed values (open dots) at Delhi (A) 1988/89 and (B) 1988/90, and Woodstock (C) 1988/89 and (D) 1989/90.

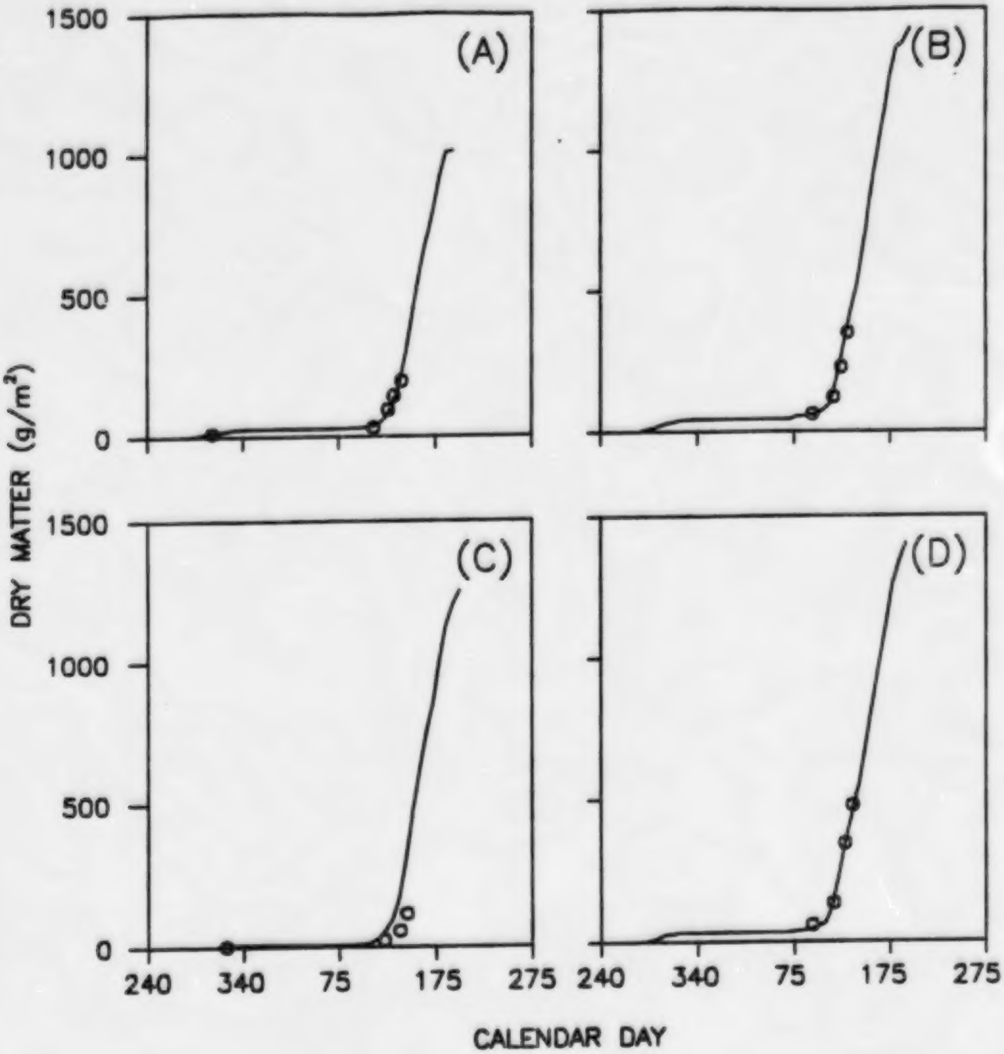

Figure C.2 - Rye dry matter accumulation simulated using the CERES-Wheat model with nitrogen subroutine deactivated (solid line) versus observed values (open dots) at Delhi (A) 1988/89 and (B) 1989/90, and Woodstock (C) 1988/89 and (D) 1989/90.

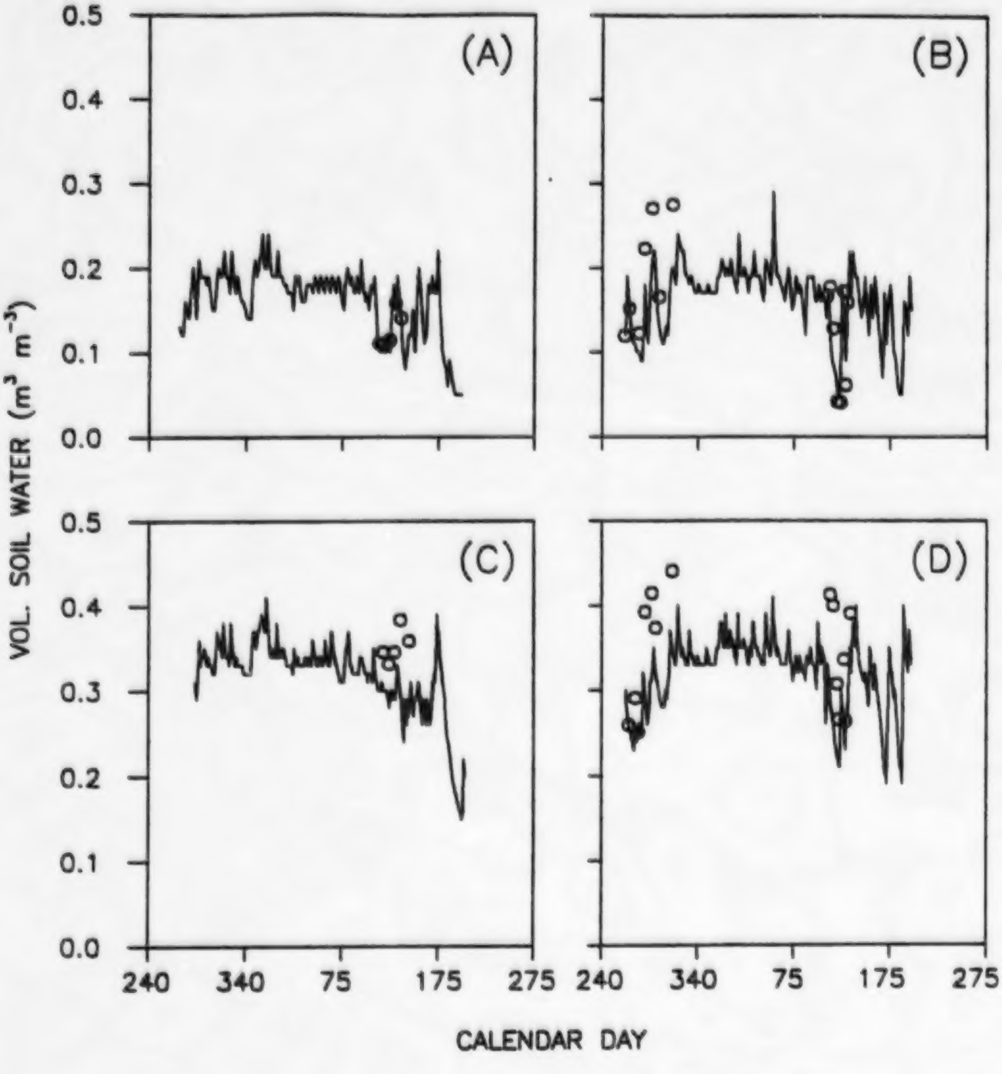

Figure C.3 - Volumetric soil water content in the surface layer (0-10 cm) under rye simulated (solid line) using CERES-Wheat versus observed values (open dots) at Delhi (A) 1988/89 and (B) 1989/90, and Woodstock (C) 1988/89 and (D) 1989/90.

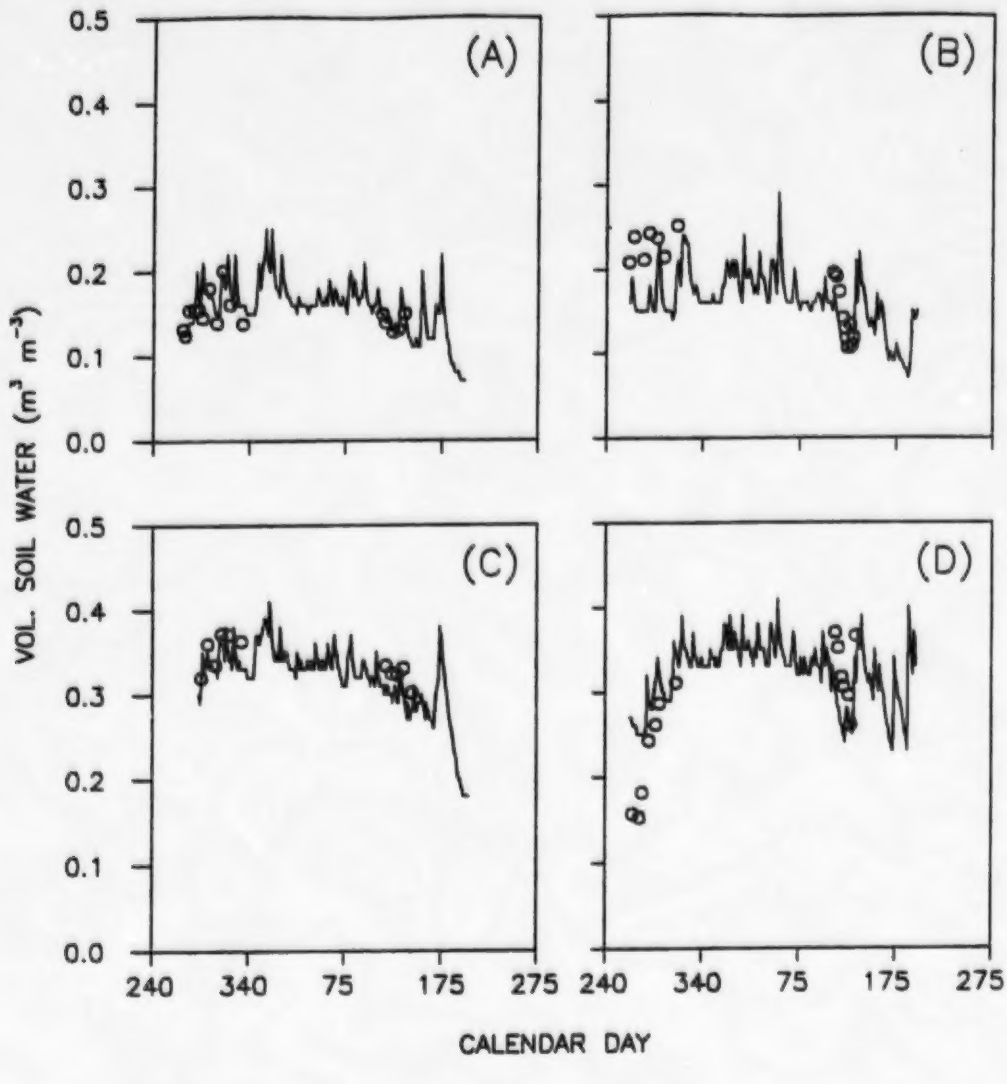

Figure C.4 - Volumetric soil water content in the 10-30 cm layer under rye simulated (solid line) using CERES-Wheat versus observed values (open dots) at Delhi (A) 1988/89 and (B) 1989/90, and Woodstock (C) 1988/89 and (D) 1989/90.

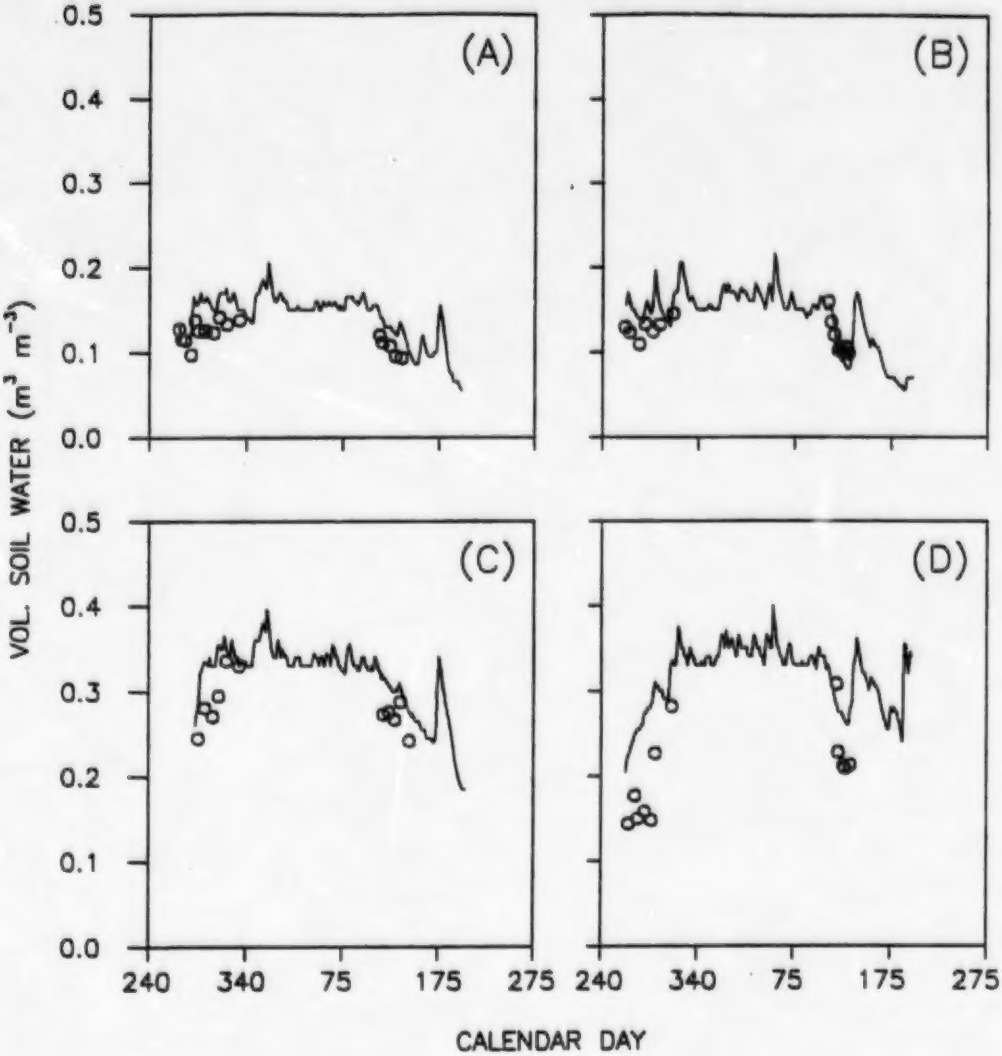

Figure C.5 - Volumetric soil water content in the 30-60 cm layer under rye simulated (solid line) using CERES-Wheat versus observed values (open dots) at Delhi (A) 1988/89 and (B) 1989/90, and Woodstock (C) 1988/89 and (D) 1989/90.

APPENDIX D

Section 3

SOYGRO simulation results (Tables)

Table D.1 - Model outputs and observed values of phenological dates for the soybean cultivar A-1937 grown at Delhi in 1989 and 1990. The genetic coefficients shown are generic for maturity group 00 cultivars.

Coefficient$		Variable	1989		1990	
Name	Value#		model	observed*	model	observed*
-	-	emergence date	155	152	159	154
VARTH VARNO	1.50 9.50	flowering date	199	189	203	192
VARTHR(10)	43.16	phys.mat. date	261	256	275	257

coefficient average
* average of three treatments
$ each coefficient shown determines the output of the variable listed in the same row.

Table D.2 - Model outputs and observed values of phenological dates for the soybean cultivar PI-0877 grown at Woodstock in 1989 and 1990. The genetic coefficients shown are generic for maturity group 00 cultivars.

Coefficient$		Variable	1989		1990	
Name	Value#		model	observed*	model	observed*
-	-	emergence date	160	157	165	163
VARTH VARNO	1.50 9.50	flowering date	206	195	208	198
VARTHR(10)	43.16	phys.mat. date	307	252	281	244

coefficient average
* average of three treatments
$ each coefficient shown determines the output of the variable listed in the same row.

Table D.3 - Model outputs and observed values of phenological dates for the soybean cultivar A-1937 grown at Delhi in 1989 and 1990. The genetic coefficients shown are generic for maturity group 00 cultivars, but TOPT1 was changed to 23.0 C.

Coefficient$		Variable	1989		1990	
Name	Value#		model	observed*	model	observed*
-	-	emergence date	152	152	154	154
VARTH VARNO	1.50 9.50	flowering date	187	189	191	192
VARTHR(10)	43.16	phys.mat. date	249	256	250	257

coefficient average
* average of three treatments
$ each coefficient shown determines the output of the variable listed in the same row.

Table D.4 - Model outputs and observed values of phenological dates for the soybean cultivar PI-0877 grown at Woodstock in 1989 and 1990. The genetic coefficients shown are generic for maturity group 00 cultivars, but TOPT1 was changed to 23.0 C.

Coefficient$		Variable	1989		1990	
Name	Value#		model	observed*	model	observed*
-	-	emergence date	156	157	162	163
VARTH VARNO	1.50 9.50	flowering date	193	195	196	198
VARTHR(10)	43.16	phys.mat. date	263	253	255	244

coefficient average
* average of three treatments
$ each coefficient shown determines the output of the variable listed in the same row

Table D.5 - Model outputs and observed values of phenological dates for the soybean cultivar A-1937 grown at Delhi in 1989 and 1990. TOPT1 was changed to 23.0 C, and VARNO fixed at the value shown.

Coefficient[$]		Variable	1989		1990	
Name	Value[#]		model	observed[*]	model	observed[*]
VARTH VARNO	2.00 0.0 9.50	flowering date	188	189	192	192
VARTHR(10)	46.95 0.411	phys.mat. date	255	256	258	257

[#] coefficient average and standard deviation
[*] average of three treatments
[$] each coefficient shown determines the output of the variable listed in the same row.

Table D.6 - Model outputs and observed values of phenological dates for the soybean cultivar PI-0877 grown at Woodstock in 1989 and 1990. TOPT1 was changed to 23.0 C, and VARNO fixed at the value shown.

Coefficient[$]		Variable	1989		1990	
Name	Value[#]		model	observed[*]	model	observed[*]
VARTH VARNO	2.50 0.0 9.50	flowering date	194	195	197	198
VARTHR(10)	36.00 0.0	phys.mat. date	252	252	245	244

[#] coefficient average and standard deviation
[*] average of three treatments
[$] each coefficient shown determines the output of the variable listed in the same row

Table D.7 - Model outputs and observed values for different variables of the soybean cultivar A-1937 grown at Delhi in 1989 and 1990. The genetic coefficients shown are generic for maturity group 00 cultivars.

Coefficient[$]		Variable	1989		1990	
Name	Value[#]		model	observed[*]	model	observed[*]
VARTHR(8)	20.30	max. LAI	1.4	2.7 0.62	2.3	4.6 1.48
PGLF	1.00	biomassR8[+] (Mg ha^{-1})	1.4	3.7 0.82	3.1	6.8 1.3
-	-	stalk (Mg ha^{-1})	0.41	0.69 0.16	1.0	1.3 0.32
PODVAR	13.0	seeds/m^2	0.47	1.4 0.31	0.9	2.5 0.46
SHVAR	9.5	pod (Mg ha^{-1})	1.0	3.0 0.67	2.1	5.6 0.97
SDVAR	6.0	seed (Mg ha^{-1})	0.73	2.2 0.50	1.4	4.2 0.74
SDPDVR	2.1	seed/pod	2.1	2.1 0.142	2.1	2.3 0.062
-	-	g/seed	0.155	0.158 0.004	0.149	0.171 0.008
-	-	HI	0.51	0.60 0.012	0.44	0.62 0.013
-	-	%shelling	72.0	73.8 1.1	66.7	76.1 0.7

[#] coefficient average
[*] average and standard deviation
[$] each coefficient shown determines the output of the variable listed in the same row
[+] harvest maturity stage.

Table D.8 - Model outputs and observed values for different variables of the soybean cultivar PI-0877 grown at Woodstock in 1989 and 1990. The genetic coefficients shown are generic for maturity group 00 cultivars.

Coefficient[$]		Variable	1989		1990	
Name	Value[#]		model	observed[*]	model	observed[*]
VARTHR(8)	20.30	max. LAI	3.2	3.3 1.1	3.2	4.0 1.7
PGLF	1.00	biomassR8[+] (Mg ha^{-1})	3.4	5.4 1.3	3.9	7.6 1.1
-	-	stalk (Mg ha^{-1})	1.9	0.9 0.25	1.4	1.3 0.32
PODVAR	13.0	seeds/m^2	0.85	2.2 0.45	1.1	2.9 0.36
SHVAR	9.5	pod (Mg ha^{-1})	1.4	4.5 1.1	2.5	6.3 0.88
SDVAR	6.0	seed (Mg ha^{-1})	0.79	3.4 0.84	1.6	4.8 0.70
SDPDVR	2.1	seed/pod	2.1	2.3 0.07	2.1	2.1 0.15
-	-	g/seed	0.093	0.151 0.007	0.142	0.161 0.001
-	-	HI	0.24	0.63 0.010	0.42	0.63 0.018
-	-	%shelling	55.0	75.5 0.9	65.3	75.0 1.1

[#] coefficient average
[*] average and standard deviation
[$] each coefficient shown determines the output of the variable listed in the same row
[+] harvest maturity stage.

Table D.9 - Model outputs and observed values for different variables of the soybean cultivar A-1937 grown at Delhi in 1989 and 1990. The genetic coefficients shown were adjusted to data obtained in 1990. PODVAR was fixed at 25 pods m^{-2} d^{-1}.

Coefficient[$]		Variable	1989		1990	
Name	Value[#]		model	observed[*]	model	observed[*]
VARTHR(8)	17.6 2.898	max. LAI	3.1	2.7 0.62	5.2	4.6 1.5
PGLF	1.75 0.098	biomassR8[+] (Mg ha^{-1})	4.4	3.7 0.82	8.0	6.8 1.2
-	-	stalk (Mg ha^{-1})	1.1	0.69 0.16	2.1	1.3 0.32
PODVAR	25.0 -	seeds/m^2	1.6	1.4 0.31	2.7	2.5 0.46
SHVAR	15.1 0.531	pod (Mg ha^{-1})	3.2	3.0 0.67	5.8	5.6 0.97
SDVAR	6.9 0.649	seed (Mg ha^{-1})	2.6	2.2 0.50	4.3	4.2 0.74
SDPDVR	2.1	seed/pod	2.3	2.1 0.14	2.3	2.3 0.05
-	-	g/seed	0.159	0.158 0.004	0.156	0.171 0.008
-	-	HI	0.59	0.60 0.012	0.53	0.62 0.013
-	-	%shelling	80.0	73.8 1.1	73.7	76.1 0.7

[#] coefficient average and standard deviation
[*] average and standard deviation
[$] each coefficient shown determines the output of the variable listed in the same row
[+] harvest maturity stage.

Table D.10 - Model outputs and observed values for different variables of the soybean cultivar PI-0877 grown at Woodstock in 1989 and 1990. The genetic coefficients shown were adjusted to data obtained in 1990. PODVAR was fixed at 35 pods m^{-2} d^{-1}.

Coefficient[$]		Variable	1989		1990	
Name	Value[#]		model	observed[*]	model	observed[*]
VARTHR(8)	11.2 1.24	max. LAI	6.2	3.3 1.1	5.7	4.0 1.7
PGLF	1.74 0.116	biomassR8[+] (Mg ha^{-1})	6.9	5.4 1.3	7.7	7.6 1.1
-	-	stalk (Mg ha^{-1})	1.8	0.93 0.25	1.7	1.3 0.32
PODVAR	35.0 -	seeds/m^2	2.5	2.2 0.45	2.7	2.9 0.36
SHVAR	11.9 0.115	pod (Mg ha^{-1})	5.1	4.5 0.38	5.8	6.3 0.88
SDVAR	9.5 0.30	seed (Mg ha^{-1})	3.9	3.4 0.84	4.4	4.8 0.70
SDPDVR	2.1	seed/pod	2.1	2.3 0.07	2.1	2.1 0.15
-	-	g/seed	0.159	0.151 0.007	0.164	0.161 0.001
-	-	HI	0.56	0.63 0.010	0.57	0.63 0.018
-	-	%shelling	77.1	75.5 0.9	75.5	75.0 1.1

[#] coefficient average and standard deviation
[*] average and standard deviation
[$] coefficient shown determine the output of the variables listed that follow in the same row
[+] harvest maturity stage.

Table D.11 - Soybean seed yields simulated for two mulch conditions (early and late rye killing dates) and a ploughed condition under various weather scenarios at Delhi.

Weather condition*			Seed yield ($Mg\ ha^{-1}$)		
1989					
May	June	July	early kill	late kill	ploughed
wet	wet	-	2.8 (3.0)[$]	2.9 (3.1)	2.6
wet	dry	-	1.6 (1.7)	1.9 (2.1)	1.5
dry	wet	-	2.8 (2.9)	2.8 (3.0)	2.6
dry	dry	-	1.3 (1.4)	1.4 (1.5)	1.4
1990					
May	June	July	early kill	late kill	ploughed
wet	wet	-	4.5 (4.7)	4.3 (4.6)	4.2
wet	dry	-	4.0 (4.2)	3.8 (4.1)	3.6
wet	dry	dry	1.9 (2.1)	1.9 (2.2)	1.5
dry	wet	-	4.4 (4.6)	3.9 (4.4)	2.5
dry	dry	-	2.2 (2.4)	-[#] (-)	2.5
dry	dry	dry	1.0 (1.1)	- (-)	1.0

* see Table 3.1 for explanation of rainfall conditions
$ numbers in brackets are seed yields when rainfall interception by mulch is 50% of maximum value (see text)
# crop died due to water stress

Table D.12 - Soybean seed yields simulated for two mulch conditions (early and late rye killing dates) and a ploughed condition under various weather scenarios at Woodstock.

Weather condition*			Seed yield ($Mg\ ha^{-1}$)		
1989					
May	June	July	early kill	late kill	plowed
wet	wet	-	4.1 (4.2)$	4.0 (4.2)	3.7
wet	dry	-	1.6 (1.9)	1.2 (1.5)	1.9
dry	wet	-	4.1 (4.1)	2.4 (2.8)	3.7
dry	dry	-	0.8 (0.8)	-# (-)	1.6
1990					
May	June	July	early kill	late kill	ploughed
wet	wet	-	4.5 (4.5)	4.4 (4.4)	4.4
wet	dry	-	4.5 (4.5)	4.3 (4.3)	4.3
wet	dry	dry	3.9 (4.1)	2.6 (2.8)	3.7
dry	wet	-	4.5 (4.5)	4.3 (4.4)	4.4
dry	dry	-	2.9 (2.9)	- (-)	3.8
dry	dry	dry	1.0 (1.1)	- (-)	1.5

* see Table 3.1 for explanation of rainfall conditions
$ numbers in brackets are seed yields when rainfall interception by mulch is 50% of maximum value (see text)
\# crop died due to water stress

APPENDIX E

Section 3

SOYGRO simulation results (Figures)

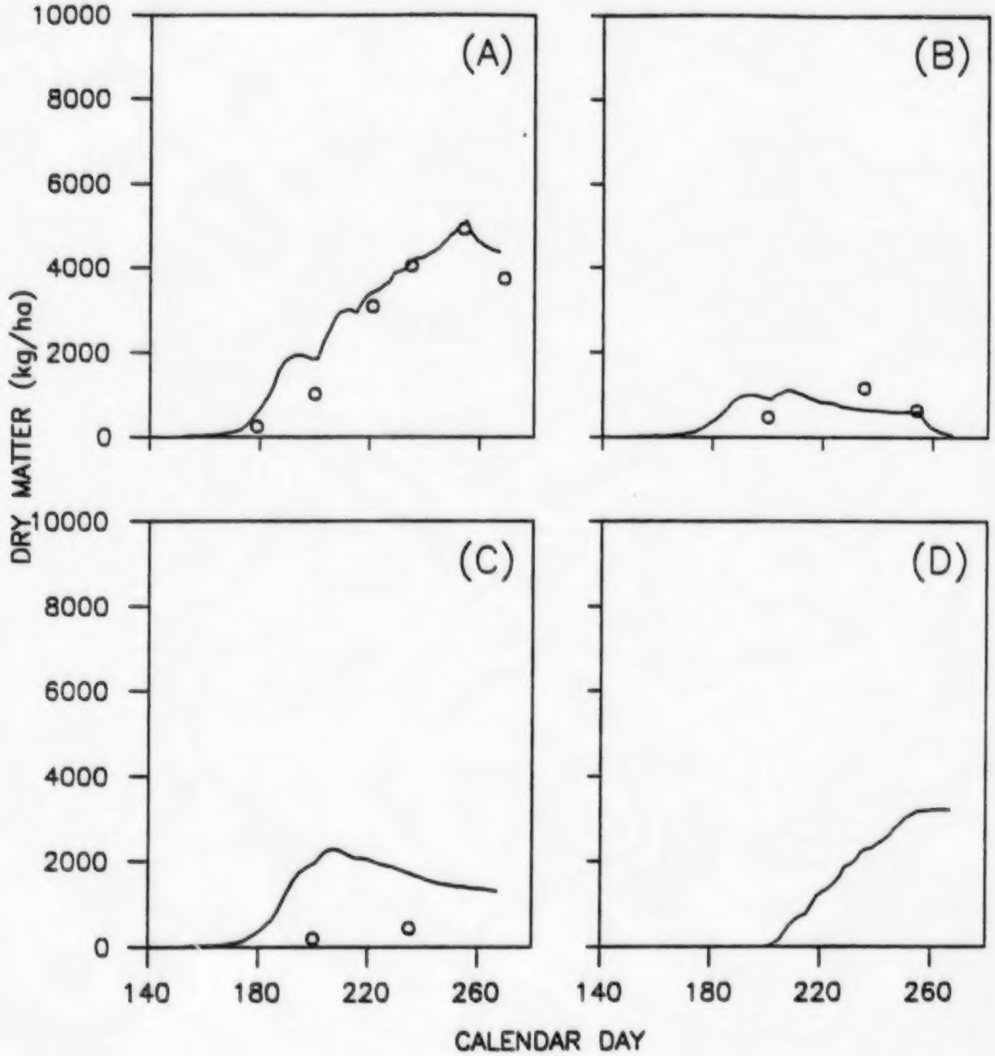

Figure E.1 - Soybean dry matter simulated using SOYGRO and genetic coefficients adjusted for variety A-1937 (solid line) with 1990 data versus observed values (open dots) at Delhi in 1989 for (A) canopy, (B) leaves, (C) roots and (D) pod growth.

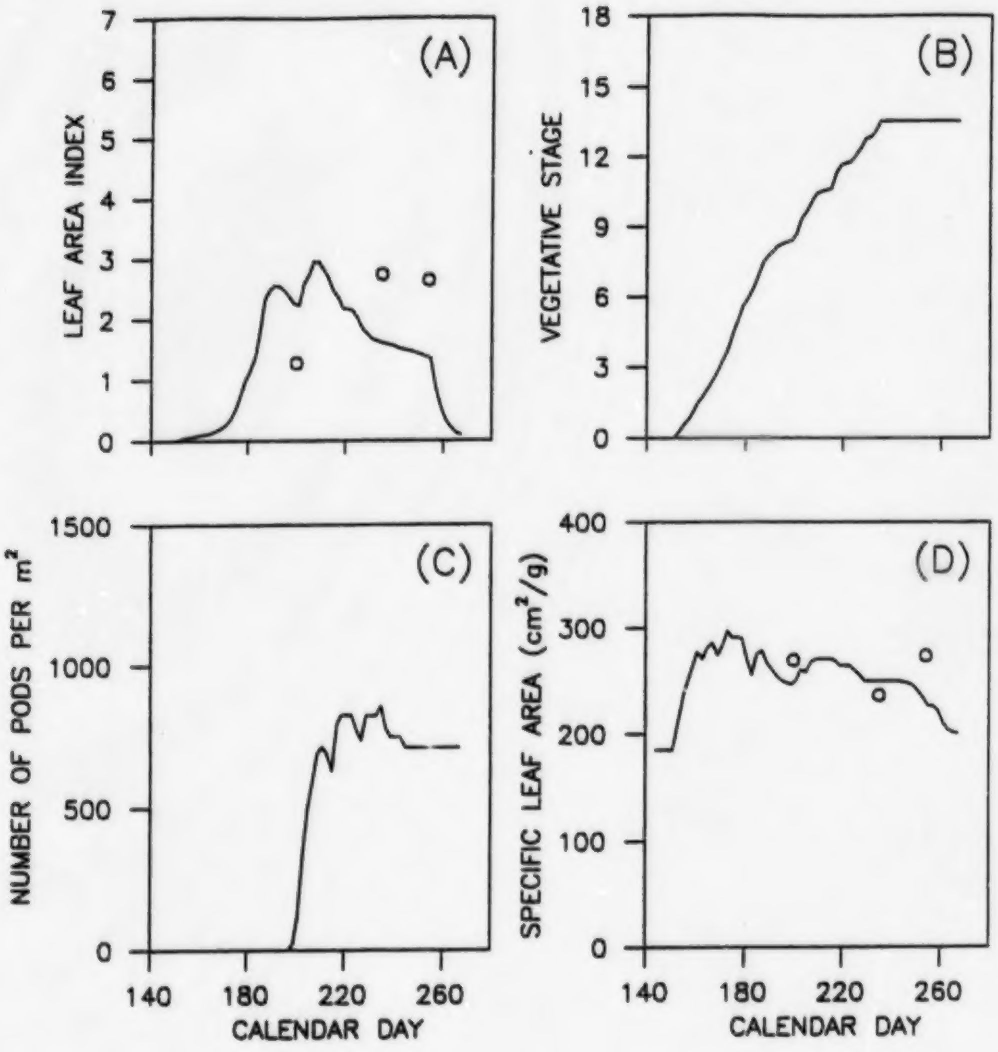

Figure E.2 - Soybean variables simulated using SOYGRO and genetic coefficients adjusted for variety A-1937 (solid line) with 1990 data versus observed values (open dots) at Delhi in 1989 for (A) leaf area index, (B) vegetative stage, (C) number of pods and (D) specific leaf area.

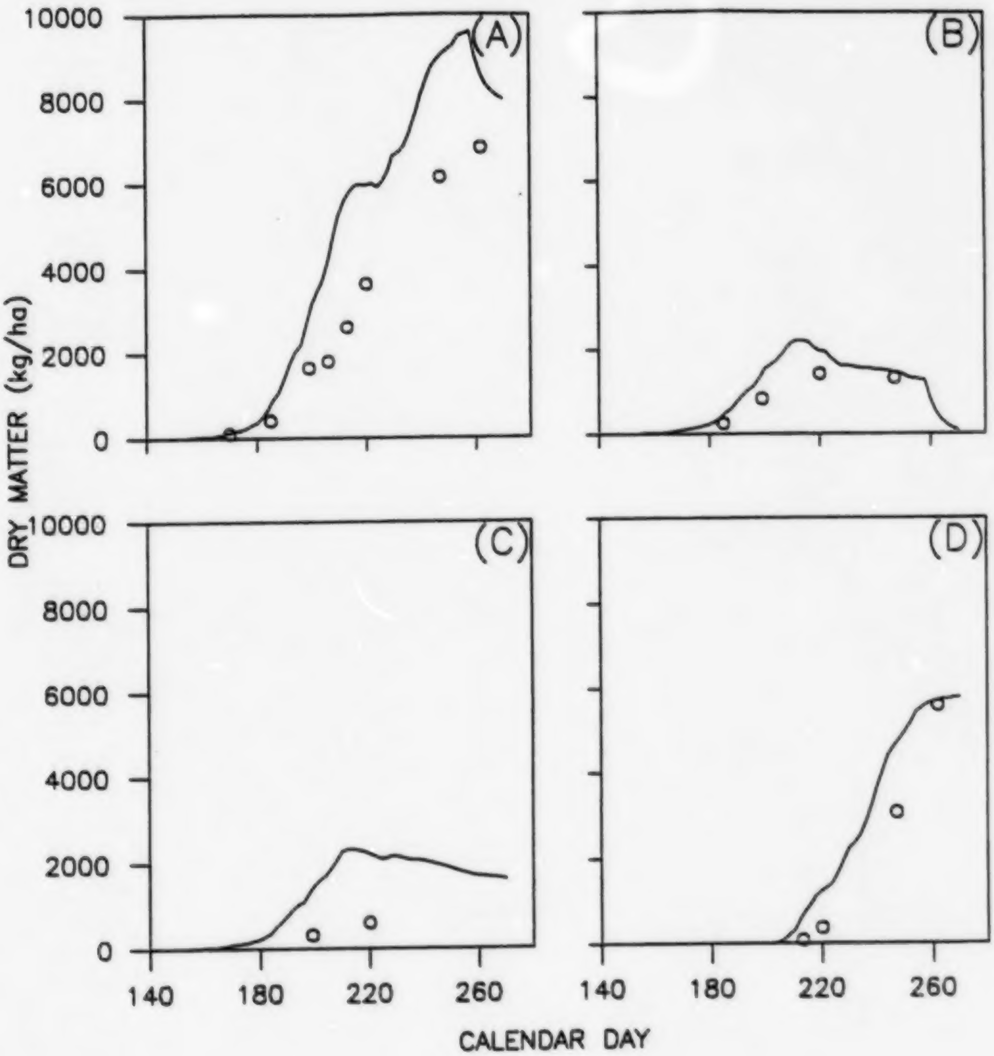

Figure E.3 - Soybean dry matter simulated using SOYGRO and genetic coefficients adjusted for variety A-1937 (solid line) with 1990 data versus observed values (open dots) at Delhi in 1990 for (A) canopy, (B) leaves, (C) roots and (D) pod growth.

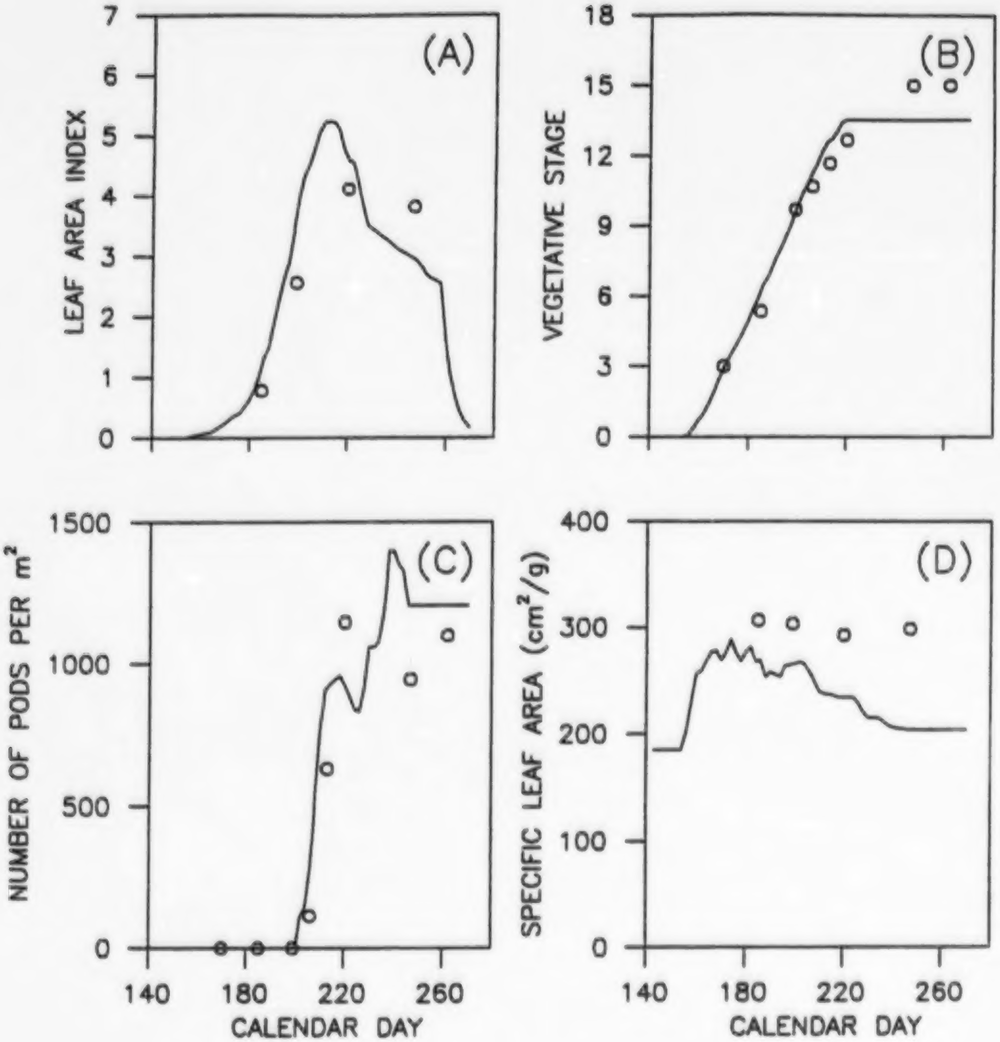

Figure E.4 - Soybean variables simulated using SOYGRO and genetic coefficients adjusted for variety A-1937 (solid line) with 1990 data versus observed values (open dots) at Delhi in 1990 for (A) leaf area index, (B) vegetative stage, (C) number of pods and (D) specific leaf area.

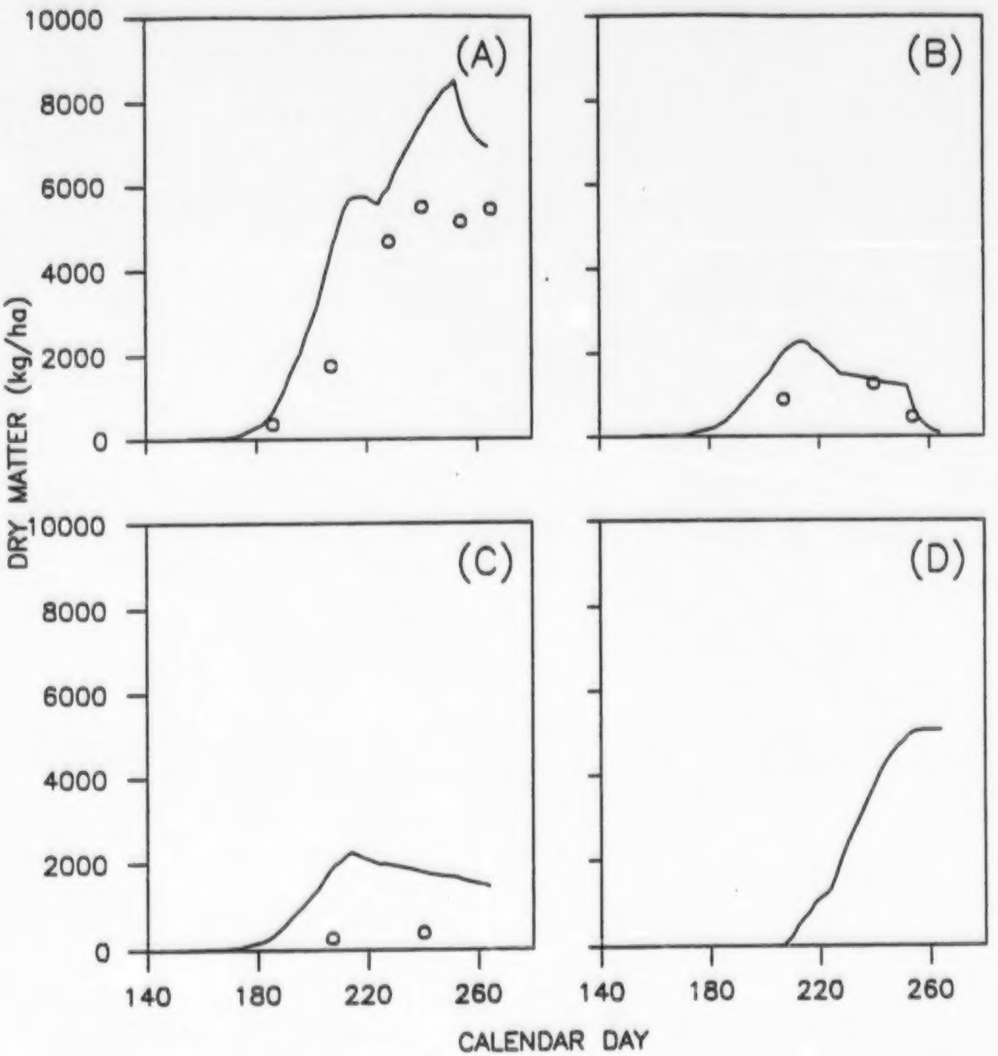

Figure E.5 - Soybean dry matter simulated using SOYGRO and genetic coefficients adjusted for variety PI-0877 (solid line) with 1990 data versus observed values (open dots) at Woodstock in 1989 for (A) canopy, (B) leaves, (C) roots and (D) pod growth.

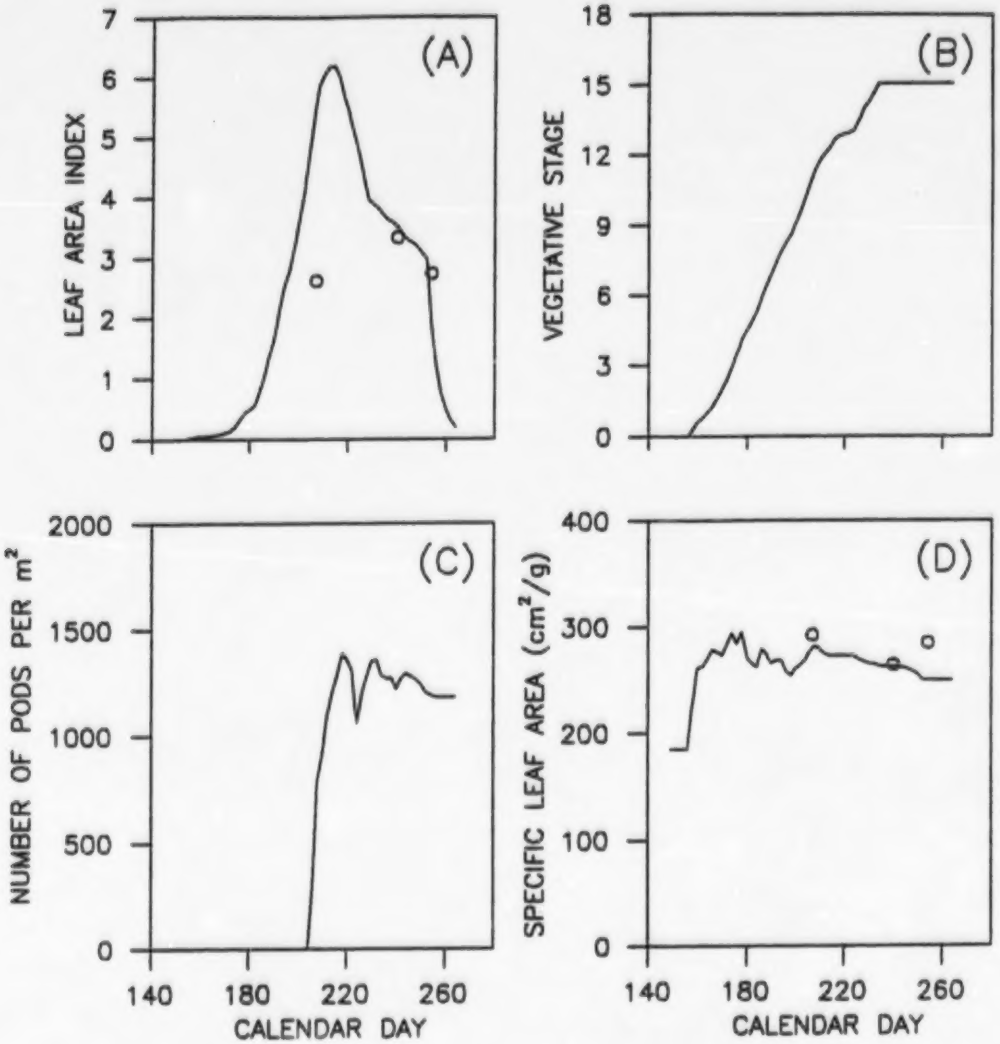

Figure E.6 - Soybean variables simulated using SOYGRO and genetic coefficients adjusted for variety PI-0877 (solid line) with 1990 data versus observed values (open dots) at Woodstock in 1989 for (A) leaf area index, (B) vegetative stage, (C) number of pods and (D) specific leaf area.

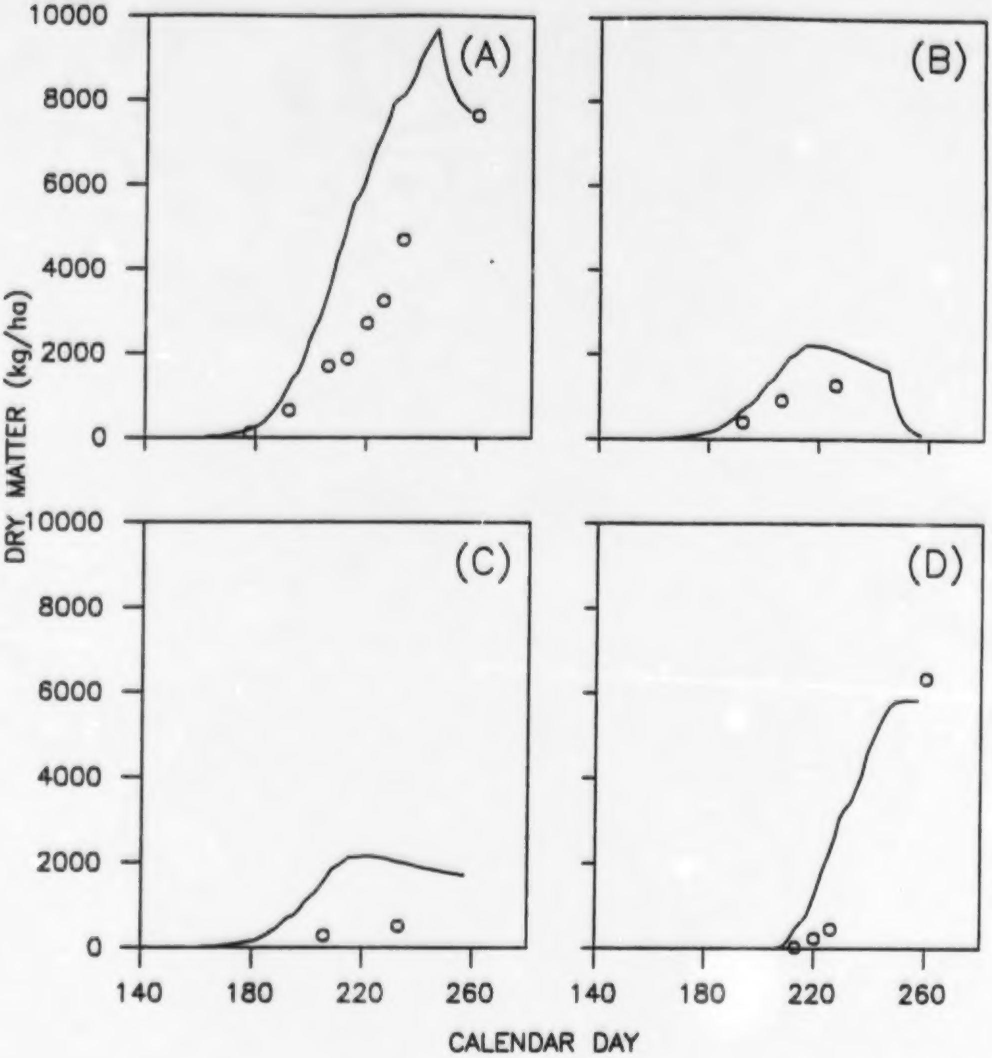

Figure E.7 - Soybean dry matter simulated using SOYGRO and genetic coefficients adjusted for variety PI-0877 (solid line) with 1990 data versus observed values (open dots) at Woodstock in 1990 for (A) canopy, (B) leaves, (C) roots and (D) pod growth.

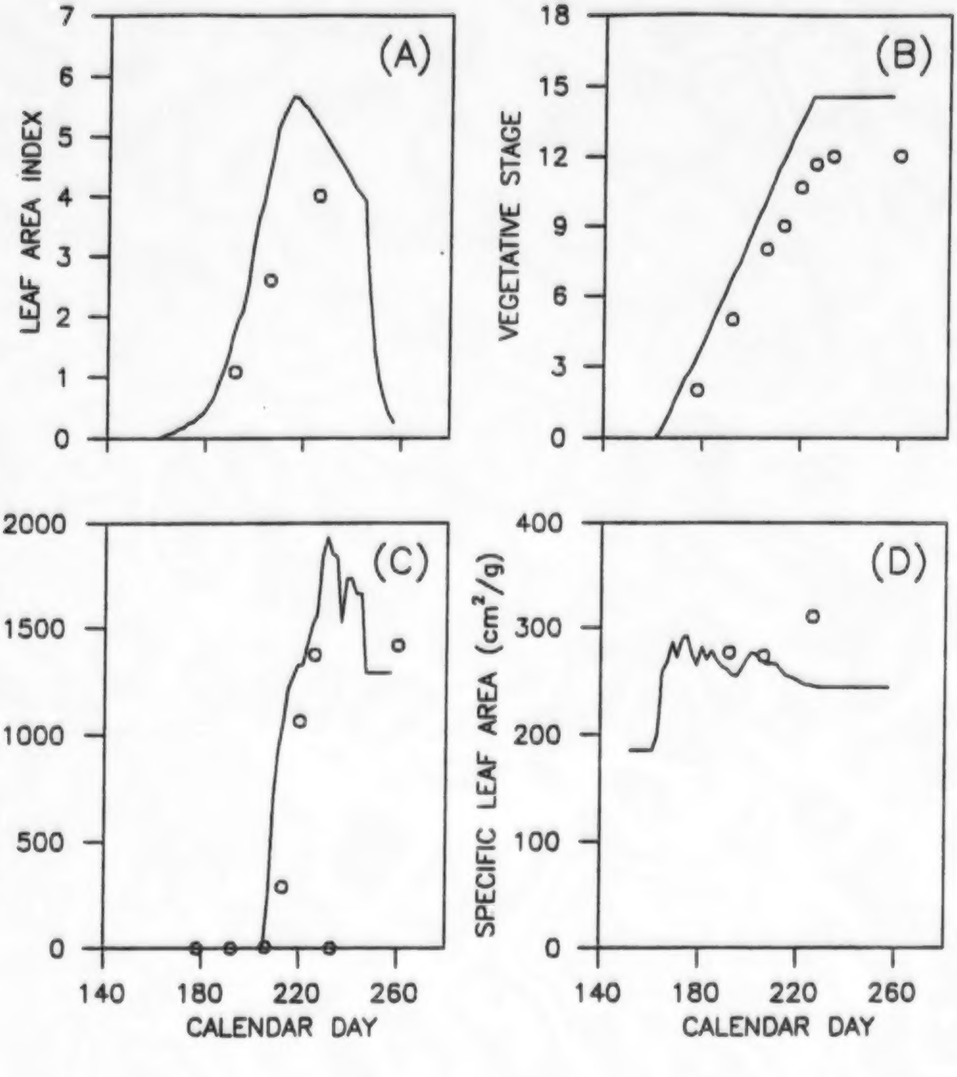

Figure E.8 - Soybean variables simulated using SOYGRO and genetic coefficients adjusted for variety Pi-0877 (solid line) with 1990 data versus observed values (open dots) at Woodstock in 1990 for (A) leaf area index, (B) vegetative stage, (C) number of pods and (D) specific leaf area.

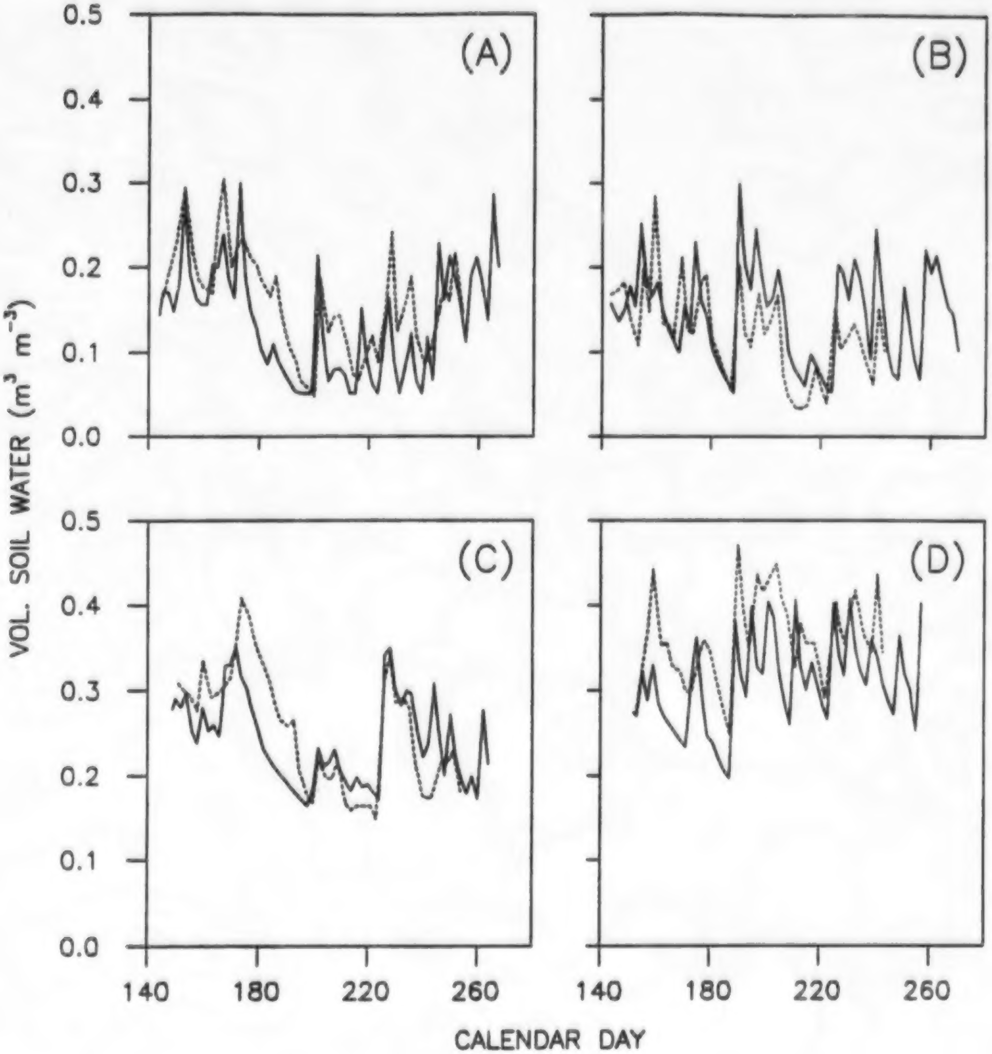

Figure E.9 - Volumetric soil water content in the surface layer (0-10 cm) under soybeans simulated (solid line) using SOYGRO, versus observed values (dotted line) at Delhi (A) 1989 and (B) 1990, and Woodstock (C) 1989 and (D) 1990.

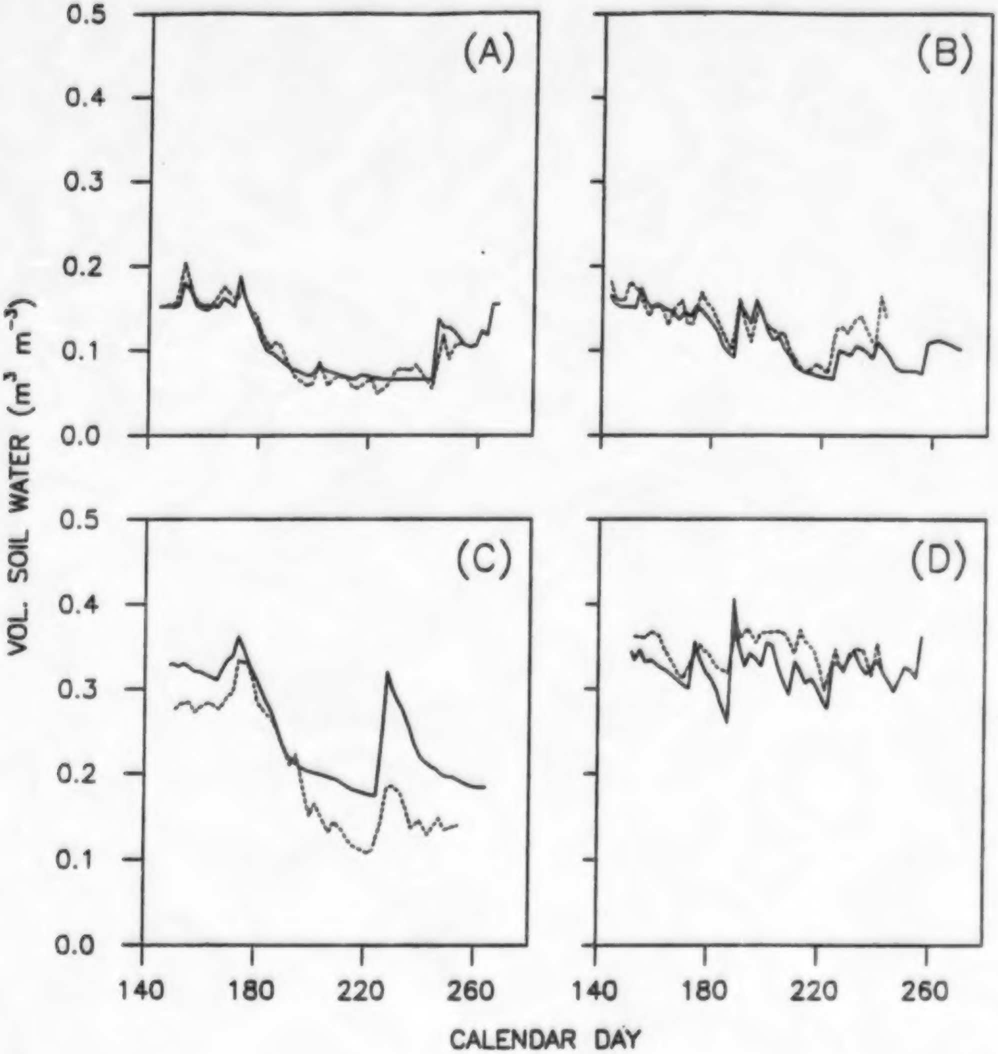

Figure E.10 - Volumetric soil water content in the 10-30 cm layer under soybeans simulated (solid line) using SOYGRO, versus observed values (dotted line) at Delhi (A) 1989 and (B) 1990, and Woodstock (C) 1989 and (D) 1990.

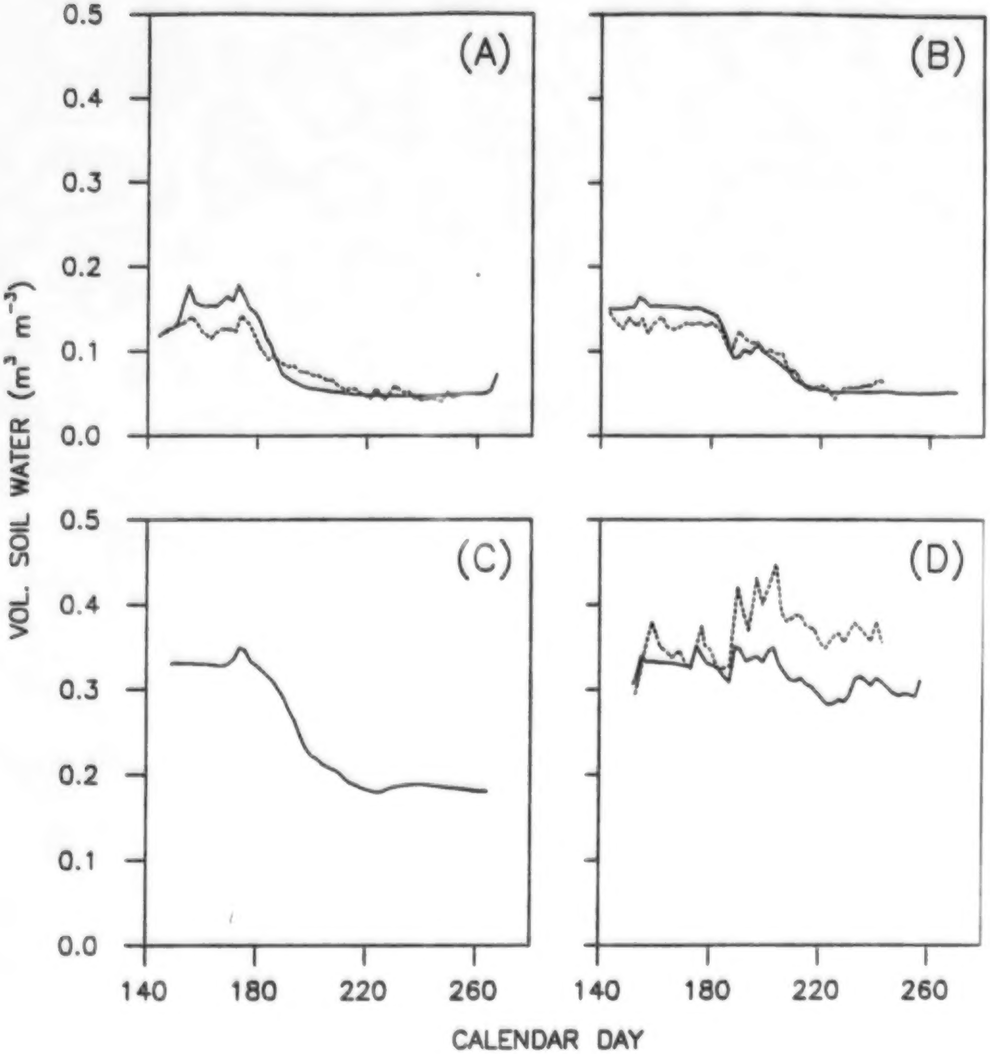

Figure E.11 - Volumetric soil water content in the 30-60 cm layer under soybeans simulated (solid line) using SOYGRO, versus observed values (dotted line) at Delhi (A) 1989 and (B) 1990, and Woodstock (C) 1989 and (D) 1990.